

TRANSACTIONS

of the
American Society
for Steel Treating

FEATURES

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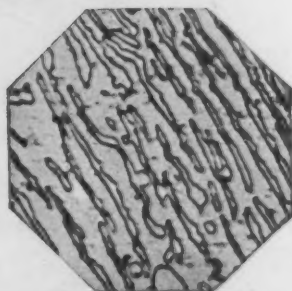
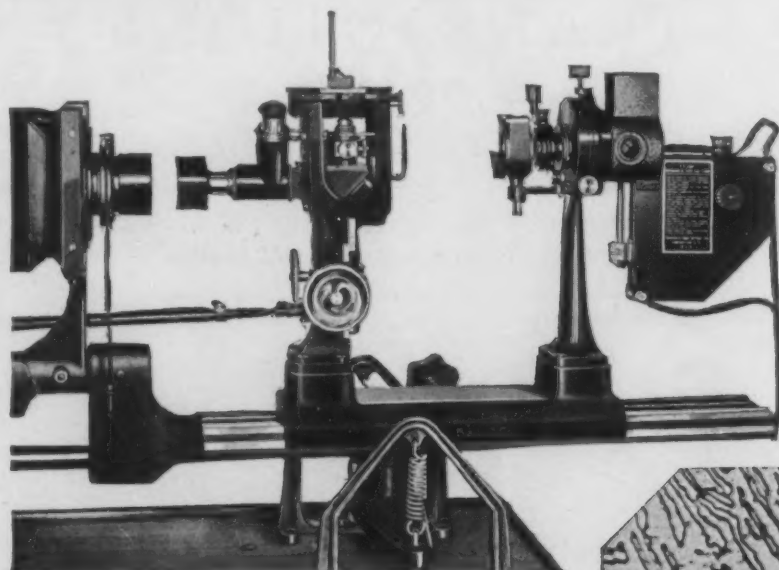
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TRANSACTIONS

American Society for Steel Treating

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JANUARY, 1929

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METHODS OF APPROXIMATING CERTAIN PHYSICAL CHARACTERISTICS OF NITRIDED STEEL CASES

BY G. M. EATON

Abstract

The paper emphasizes the need for inspection testing of nitrided products. It shows that the vital characteristics of the case are hardness and ductility. Photomicrographs are given showing the impressions produced on the nitrided case by practically all the recognized hardness testing machines. These impressions are briefly discussed and the fact is brought out that the Vickers diamond indenter hardness tester gives the clearest distinction between the brittle and ductile characteristics of nitrided cases. The paper ends with a warning that there is danger of unnecessary failures which will tend to discredit nitrided products in general if heavy production is entered into without adequate inspection testing.

SOME of the questions which are asked by the production engineer who is considering the application of nitrided steel to his product are as follows:

1. How hard is the case of nitrided steel?
2. How thick is the case of nitrided steel?
3. How does the hardness shade off from the surface to the core?
4. Is this case absolutely brittle?
5. Do different treatments, etc., produce varying shades of

A paper presented before the tenth annual convention of the society, held in Philadelphia, October 8 to 12, 1928. The author, G. M. Eaton, a member of the society is associated with the Molybdenum Corporation of America, Pittsburgh. Manuscript received July 9, 1928.

brittleness verging from absolute brittleness toward ductility?

6. Is it necessary in commercial production to apply inspection tests to the product to insure satisfactory service performance?
7. If inspection is essential, how can it be carried out?

While they are perfectly fair questions, they were asked a great many times before a practical and convincing method was found for answering them.

This paper outlines a number of methods which have been used or suggested for approaching the desired answers, and analyzes their shortcomings. It then describes the method employed by the corporation represented by the author in its research in connection with the development of nitrided steel and its applications.

The paper contains no discussion of the steel as such nor does it deal with the nitriding process, but it takes up only the problem confronting the testing engineer or the inspector on whom is laid the duty of finding out whether a nitrided product possesses the characteristics which justify the expectation that it will perform satisfactorily in a given service.

DESIRED CHARACTERISTICS

Before searching out the way to recognize the desired characteristics, it is logical to determine just what the vital characteristics are, and as a preliminary to this it is essential to define clearly the reason for the nitriding of steel. The reason for nitriding steel is to give to industry ferrous articles having surfaces which in appropriate services are resistant to wear in a degree hitherto unknown, and which are very highly resistant to corrosion under a wide variety of conditions. The paper deals only with methods for determining the fitness of nitrided products to resist wear.

Comparatively little is known about the phenomena surrounding the wear of metals. A study of the data which have been accumulated on this subject, however, points rather directly to the tentative conclusion that something more than hardness alone is required to give to metal the ability to resist wear. It seems to

be well established that ductility or toughness is also an essential characteristic for wear-resistant metal.

Resistance to wear when lubrication is faulty or entirely lacking is also a function of coefficient of friction as well as of the characteristics of the metal under various degrees of temperature elevation. The paper, however, makes only such reference to the actual characteristics as is germane in analyzing the fitness of various methods for approximating these characteristics. Our interest then for the present must center on the two characteristics, hardness and toughness of the case of nitrided steel.

As this new material is applied in industry in progressively broader fields, the mechanical engineer will inevitably demand the complete line of information he has available on the characteristics of his present commercial steels. While it is our purpose in this paper to deal specifically with only the case of nitrided articles, it seems constructive to include the applicable portion of the program laid out in connection with our research on the general subject of nitriding. This will show clearly that there exists a wide field of variables which play a part in determining the characteristics of nitrided articles.

DISTORTION

The following tabulation was compiled with the thought that the items listed would cover most of the points demanding consideration in forming sound judgment as to the necessary pre-treatment for stress relief in order to hold distortion within predetermined limits during the nitriding treatment. The work divides itself into three classes.

- A—No Pre-treatment—Rough Machining—Finish Machining—Nitriding.
- B—Pre-treatment of stock—Rough Machining—Finish Machining—Nitriding.
- C—Pre-treatment of stock—Rough Machining—Second Pre-treatment—Finish Machining—Nitriding. Tables I and II.

It is quite evident that the test engineer cannot apply a single simple test and draw the conclusion from a uniform result that the product is or is not fit for service. This is due to the fact that different service requirements demand cases with different

Table I

STOCK..	STATE.....	{	As Cast.....	{	Segregation	{	Ingotism
			Structure.....	Residual stress	Grain size		
		{	As Worked	{	Hot.....	Temperature	
	Plastically.....		Amount				
	HEAT TREATMENT..	{	Stress relief	{	Rate	Localization	
			Structure (Case		Symmetry		
			(Core		Residual stress		
			Machinability		Amount		
		{	Amount	{	Rate	Residual stress	
	Rate	Cold.....					
	REMOVAL BY MACHINING..	{	Symmetry	{			
			Localization				
			Residual stress				
			Before machining.....				
	SHAPE.....	{	Machined.....	{	Rough.....	{	Mass
Symmetry							Complexity
{			{		Stability		
						Mass	
						Symmetry	
						Complexity	
{			{		Stability		
						Mass	
						Symmetry	
						Complexity	
{	Finish.....	{		Stability			
					Permissible Distortion		
Nitrided.....							

characteristics and the economic considerations involved will unavoidably dictate that the least costly case that will work satisfactorily shall be produced. Also sane practice will demand a practical way of recognizing that this ideal case has been produced within reasonable tolerances.

HARDNESS TESTS

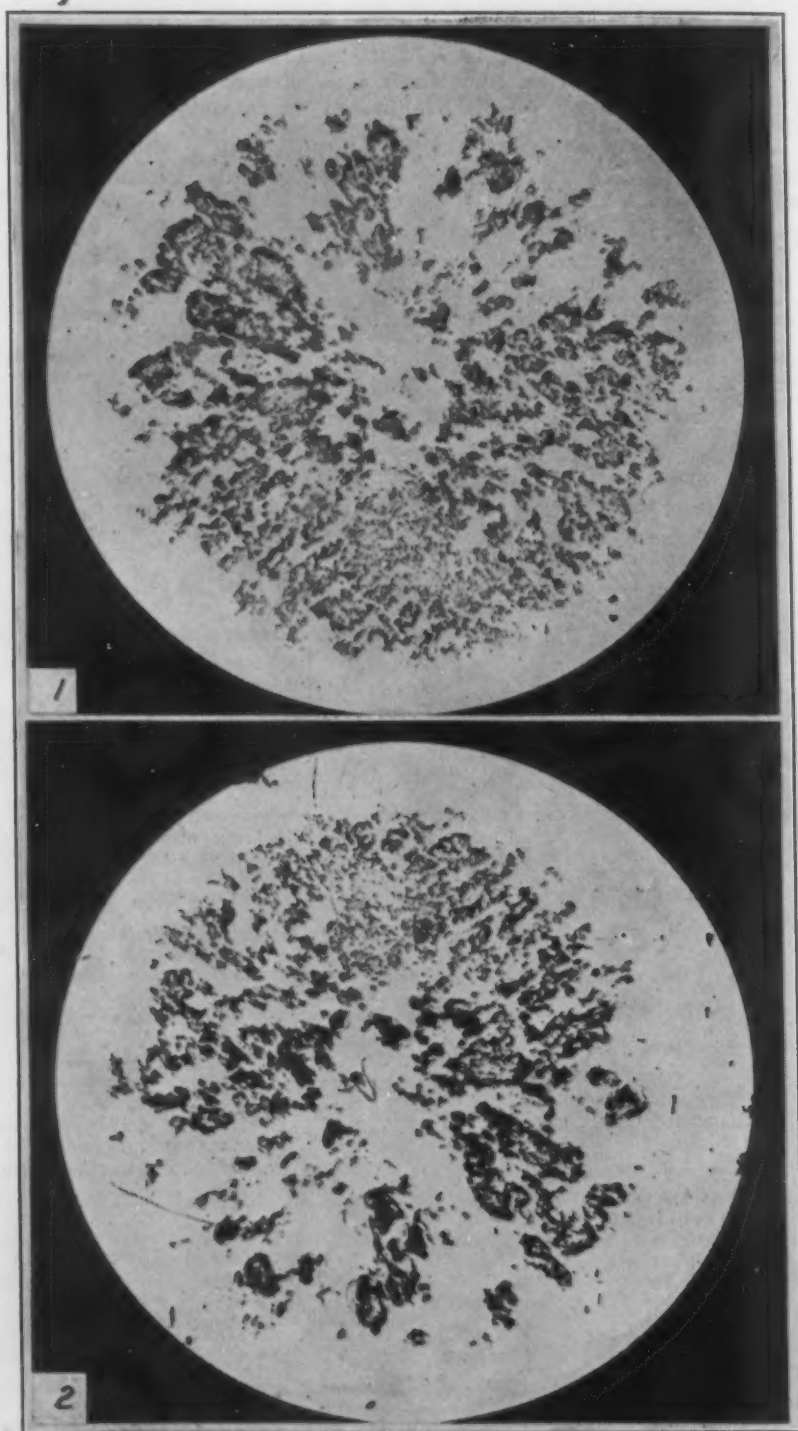
File Test. The unique hardness of the nitrided case has been recognized qualitatively for many years. The first test which we saw and used was the file test. This shows that the product possesses some measure of hardness but it fails completely to define the degree of hardness. Furthermore it is utterly erratic because the first pass of any file we have been able to find, over a case with a hardness of say 700 to 800 Brinell, ruins the keen cutting edge of the file, so that it will refuse to cut a materially softer case on subsequent passes. This is well illustrated by a comparatively

Table II

The following tabulation constitutes a condensed summary of tests. A number of the items listed will be elaborated on to some extent later in the paper.

STOCK BEFORE NITRIDING		STRENGTH AND DUCTILITY	Pulling tests on standard test pieces	Proportional limit Ultimate strength Elongation Reduction	Range of Temperature
		ENDURANCE	Fatigue tests	Farmer Cantilever	
		IMPACT	Izod-Charpy		
CORE AS NITRIDED OVER SIZED WITH CASE REMOVED		STRENGTH AND DUCTILITY	Pulling tests	Proportional limit Ultimate strength Elongation Reduction	Range of temperature
		ENDURANCE	Fatigue tests	Farmer Cantilever	
		IMPACT	Izod-Charpy		
CASE		STRENGTH AND DUCTILITY	Pulling tests on Thin wires Thin strips Thin tubes	Proportional limit Ultimate strength Elongation Reduction Modulus of elasticity	Range of temperature
			Bend tests on Strips of Assorted Thickness.	Relative radius of curvature	
		HARDNESS AND PENETRATION		Scleroscope Brinell Rockwell Herbert pendulum Diamond scratch Vickers diamond indenter	Range of temperature
CASE AND CORE COMBINED		STRENGTH AND DUCTILITY	Pulling tests on Std. test pieces..	Proposed limit Ultimate strength Elongation Reduction Corrosion crack test	Range of temperature
			Bend tests on thick strips	Proportional limit Ultimate strength Corrosion crack test	Range of temperature
		ENDURANCE	Fatigue Tests	Farmer	Cantiler
		IMPACT	Izod	Charpy	
COEF. OF FRICTION	NITRIDED CASE AGAINST.	Nitrided Case Babbitt Bronze Steel Cast Iron	}	Lubricated and Dry	Range of temperature Also at different depths below outer nitrided surface
CORROSION ...		Atmosphere Commercial acids Commercial alkalis Sulphur oil Salt Spray Wet and dry cycle Dilute acids Dilute alkalis Hot Gases	At different temperatures and different depths below outer nitrided surface.		

recent occurrence where a case was reported to us as hard by file test, and we found that a new file would cut through the entire case, though with some difficulty. The product was entirely un-



Figs. 1 and 2—Photomicrographs of Scleroscope Impressions Made on Polished Surface of Ductile and Brittle Nitrided Cases, Respectively. $\times 200$.

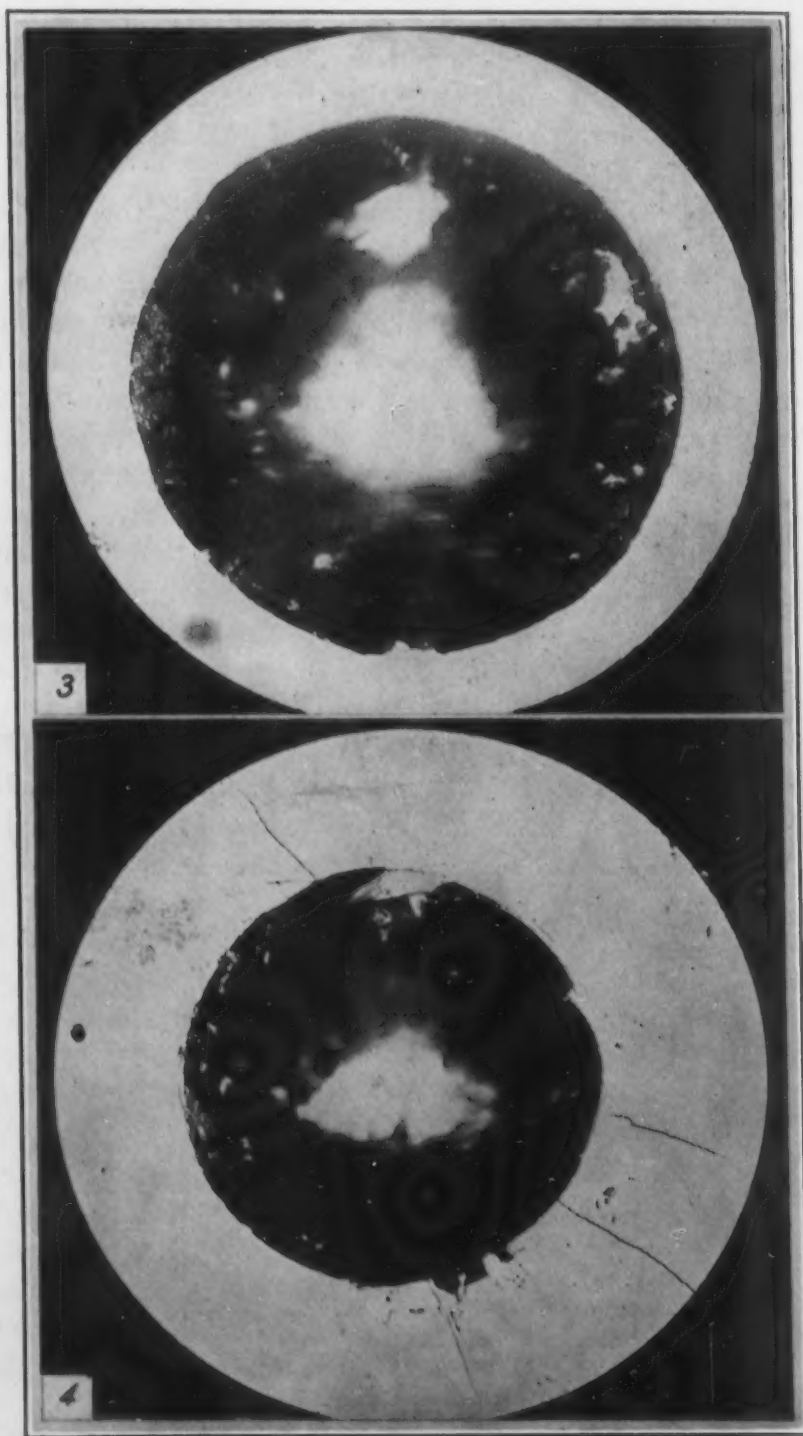
satisfactory and condemnation was necessary. This case was below 700 Brinell, on the outer surface. We found very early in our research that something better than the file test must be worked out before a conservative development of the nitriding art was possible.

Scleroscope Test. The ease and quickness of the scleroscope test makes it tempting, but the varying hardness of nitrided case prohibits its use, as under the best conditions of set-up, with a very heavy anvil under the specimen, it is entirely possible to secure the same reading on two cases of radically different surface hardness and internal hardness gradation.

Figs. 1 and 2 show photomicrographs of scleroscope impressions taken at 200 diameters magnification on the polished surface of ductile and brittle nitrided cases respectively. It will be seen that there is some ground for suspecting that the working surface of the diamond has become minutely chipped in service. This, however, is comparatively unimportant in this connection. The vital point is that the scleroscope draws no adequate distinction between the ductile and the brittle cases.

Brinell Test. The hardest steel Brinell ball is far too soft for use with nitrided steel. The diamond ball offers some possibilities, particularly with very small balls, but here again the varying hardness is hostile. Unfortunately we were not successful, in the time available after starting to write the paper, in locating a baby Brinell machine equipped with a diamond ball. The machine used had a hard steel ball. A comparison of impression showed an insufficient difference to permit distinguishing between a ductile and a brittle case when using a hard steel baby Brinell ball. It is possible that a diamond ball would give more satisfactory results, although we doubt this.

Rockwell Test. The Rockwell C diamond offers a better approach to the characteristics of the nitrided case although here again the varying hardness is inimical. Also the stability of the diamond in this severe service remains to be proven. Figs. 3 and 4 show photomicrographs of Rockwell C impressions (with 60-kilogram loading) taken at 200 diameters magnification on polished surfaces of ductile and brittle nitrided cases respectively. The impression in Fig. 3 is surrounded with pasty flow. The impression in Fig. 4 shows no great degree of spalling. There are, how-



Figs. 3 and 4—Photomicrographs of Rockwell C Impressions Made on Polished Surface of Ductile and Brittle Nitrided Cases, Respectively. Fig. 3 150 Kilogram Loading and Fig. 4 with a 60 Kilogram Loading. $\times 200$.



Fig. 5—Photomicrograph of Scratches Made with a Sclerometer, Using Sapphire Point, on Ductile Nitrided Case. $\times 200$.

ever, a few very definite cracks in the case showing that the case of Fig. 4 is more brittle than that of Fig. 3. The usual 150-kilogram loading was used at first, but was found to be entirely too heavy. This showed considerably more cracking. Loading of 60-kilograms is still undesirably heavy as a great range of hardness is involved in the penetrated material. It seems logical, however, to believe that if a materially lighter loading, say 10 kilograms, had been used, there would have been no appreciable distinction between the ductile and the brittle cases.

Diamond Scratch Test. We tried this method in the early stages of our research and while the results were not satisfactory, our criticisms were directed to details which were in no way fundamental. It seemed logical to believe that some of the recent scratch instruments might offer a very good research tool for studying hardness penetration. This method, however, does not appear to

lend itself to production work, as micro polish is essential. Also the results of the tool require interpretation into recognized hardness numbers if they are to be intelligible to industry. The ability of the diamond to stand up properly for any length of time against the nitrided case remains to be proven.

To show what may be expected of the scratch method, we have included Fig. 5. This figure shows a photomicrograph taken at 200 diameters of the work of the Sclerometer with the sapphire point on a ductile nitrided case. The scratch is difficult to measure with any great degree of accuracy and we know of no translation into recognized hardness numbers. It does, however, give a good general idea of the tapering hardness of the case and it can be taken very quickly after the test piece has been polished. There is practically no recognizable difference in the character of the scratch in the ductile and brittle cases.

Herbert Pendulum Test. The Herbert pendulum with a diamond ball probably offers the most accurate means now available for determining the hardness of the nitrided case. There are, however, very serious objections to its adoption for commercial work, as follows:

1. The harder the case the more important it is that the surface be smooth. But the nitrided case is of such extreme hardness that with commercially smooth grinding, irregularities of oscillation occur which can easily be recognized by the eye of a skillful operator, and micro polish is really necessary for good results.

2. This instrument requires more skill on the part of the operator than it is customary to expect of men doing routine testing.

3. With the Herbert pendulum we failed to detect an adequate distinction between brittle and ductile cases.

4. We were not successful in devising a practical way of placing the instrument in accurately spaced locations for exploring the gradation of hardness of the case. The precise meaning of this statement will be cleared up in the description of the methods for making this exploration with the Vickers machine. It is probable that means for locating successive readings in accurately spaced relation can be devised, but in our judgment the failure of the instrument to give some measure of ductility is of itself sufficient reason for considering it impractical as a means for testing nitrided cases.

Vickers Diamond Hardness Tester. This machine is in our judgment the best available instrument for demonstrating the fitness of the nitrided case for service. The tapering hardness is of course objectionable. If the case shades down in hardness from the extreme surface, it is obvious that all the readings will be low, since the tip of the diamond will be in softer material than the surface material. In spite of this, however, we have taken a reading on a nitrided case of 1310 Brinell with this machine. The reading at the surface was the highest reading we found on this piece. The conversion table supplied with the machine reads to 1300 and a slight extrapolation was made to secure this high reading. We may note here that the case does not always possess the maximum hardness at the surface, but sometimes rises in hardness to a maximum somewhat below the surface and then grades off to the core. In this condition the Vickers, Rockwell, and Brinell credit the surface with hardness somewhat higher than it actually possesses, and the Herbert would offer the most accurate determination. This error, however, we find to be outside the realm of practical importance, with the work we have done to date using the Vickers machine.

We have adopted the Vickers machine as our present standard method for the analysis of the vital physical characteristics of the nitrided case. The detailed methods we have evolved will be discussed later.

Having found a practical method of testing for hardness and ductility, we abandoned at least temporarily our effort to secure the necessary indications by other means. We recognized the possibility of learning how to interpret the readings of other instruments than the Vickers. It would be of great commercial advantage to be able to interpret the results of hardness testing machines now broadly used by industry in the United States and we sincerely hope that other investigators will evolve ways of making practical use of either the Brinell or the Rockwell machines.

DUCTILITY

Brief reference has been made to the fact that the Vickers machine gives some insight into the ductility of the nitrided case. Before this fact was realized a great deal of time and thought was given to the attack on this problem.

Pulling Small Wires. There are in existence some very clever small tension test machines for making pulling tests on fine wires, and at first thought it seemed logical to nitride wires so small that they would consist only of outer case. This to be followed by wires of progressively larger diameter. The elastic limit and ultimate strength, modulus of elasticity, etc., could then be determined, and the elongation and reduction of area could perhaps be approximated. There is, however, the strong possibility of grave error in this procedure. With a small wire the attack of the nit-

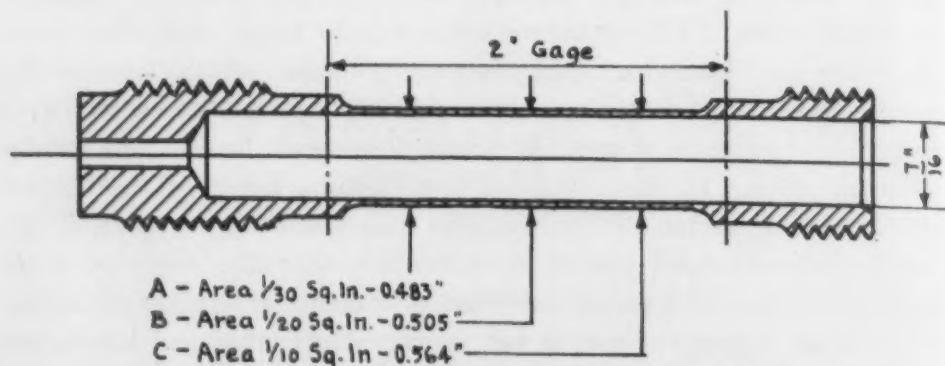


Fig. 6—Diagram Showing Thin Tube Pulling Test Piece.

riding gas on the metal is so radically different in terms of the ratio of superficial area to the mass of the metal that we did not dare to consider the test representative of far larger bodies, and this thought was abandoned for the present. It may be a reliable test, but this would have to be proven.

Bending Thin Strips. Thin strips of varying thickness could be bent to varying curvatures, and the radius of curvature of permanent set and of rupture could be determined. This was tried in a rather crude manner, but the refinements of the method employed were not sufficient to detect the presence of any ductility, no permanent set being detected before rupture occurred. Our later investigations convince us that there is a theoretical possibility of developing this method to the point where it might give some idea of relative ductility of various samples. No quantitative values for elastic limit or ultimate strength can be secured by this method, however, until the modulus of elasticity has been determined. This method is not as wide open to possible error due to the area to mass ratio mentioned above, but this question is pres-

ent in a lesser degree since over impregnation as well as stress concentrations will probably occur at the edges.

Pulling Thin Strips. The stress concentrations existing at the edges of thin brittle strips in tension led us to the conclusion that

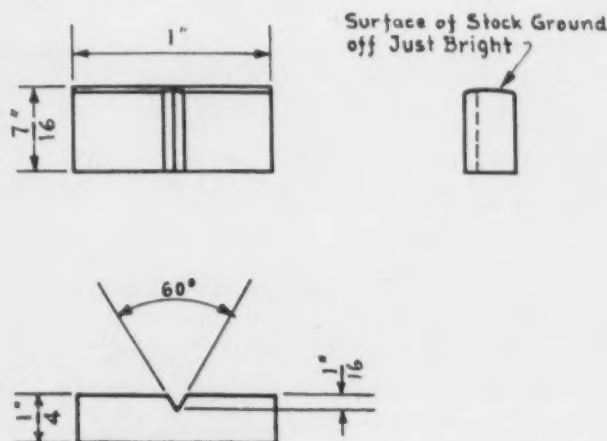


Fig. 7—Diagram Showing Standard Nitrided Test Piece Taken From Round Bar Stock, Smooth Ground All Over.

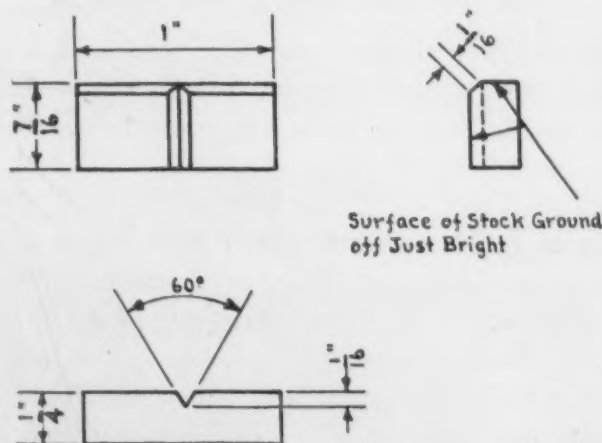


Fig. 8—Diagram Showing Standard Nitrided Test Piece Taken From Square Bar Stock, Smooth Ground All Over.

the results of this test would be quite unreliable, and the idea was abandoned.

Pulling Thin Tubes. We developed a series of three thicknesses of tubular tension test pieces, as shown in Fig. 6. This type of test piece is free from serious over-impregnation and stress concentration complications. These tubes we planned to set up in the nitriding furnace so that the gas entered the retort through the tubes and then circulated in the retort outside the tubes, thus in-

asuring thorough nitriding both inside and outside. These tubes were then to be pulled in the tension testing machine, with the idea that if they possessed appreciable ductility there would be a measurable collapse of the tube, akin to a reduction of area of a standard tension test piece. The expense and difficulty of preparing such precision test pieces and the brittleness developed in bend tests resulted in this test being also laid on the table, hoping to evolve something of a more practical nature and after experimenting extensively with the Vickers machine, we concluded that we had found what we were looking for.

When the time comes that it seems to be essential to evaluate

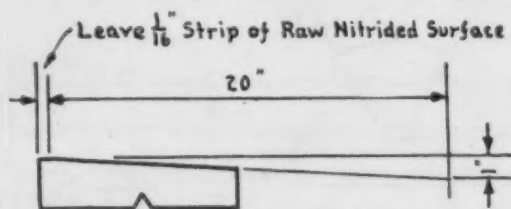


Fig. 9—Diagram Showing Standard Nitrided Test Piece Taper Ground for Case Exploration.

the proportional limit, ultimate strength, and modulus of elasticity of the nitrided case, the thin-walled tubular tension test piece offers the best means that we have been able to devise to date.

STANDARD TEST PIECE

Figs. 7 and 8 show the standard test pieces which we have adopted. They are different from each other only in the shape of the stock from which they are taken, Fig. 7 being from a round bar and Fig. 8 from a rectangular bar. The reason for making this difference was that it seemed to us to be a logical precaution to find out whether there was any difference in the nitriding action between the outer surface of a rolled bar and surfaces buried in the body of the bar as rolled.

These pieces are subjected to the nitriding treatment and are then taper-ground as shown in Fig. 9. This grinding is carried out very slowly under a heavy air blast which holds the temperature of the body of the test piece below 212 degrees Fahr. to insure that no change of structure occurs. This taper grinding exposes the case to hardness-penetration investigation with the Vickers machine. We have adopted a standard taper of one to twenty for this study. Fig. 10 shows the way in which this test piece develops

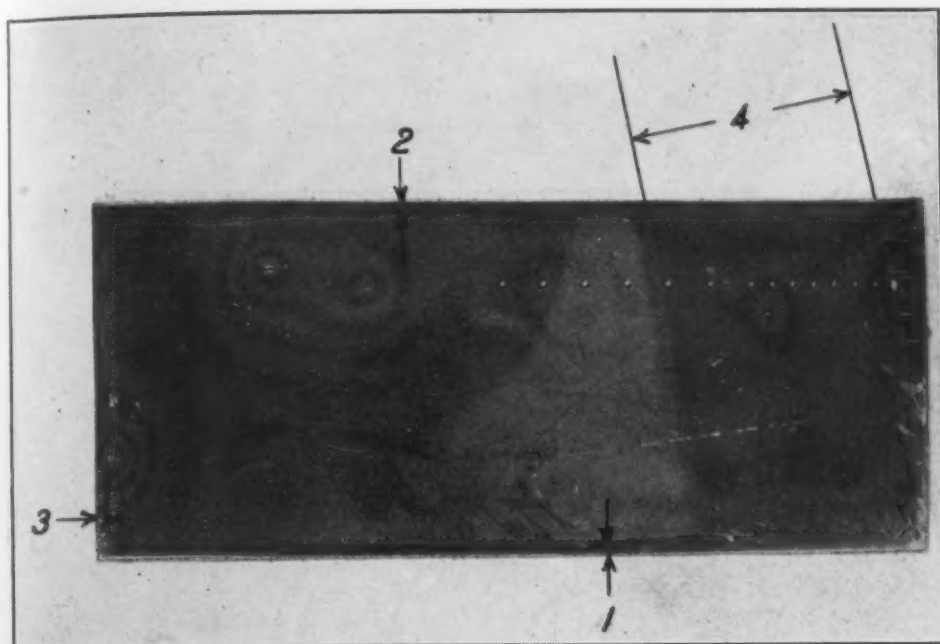


Fig. 10—Photograph of a Standard Nitrided Test Piece Showing Plan View of Case as Exposed by Grinding, etc. (1) Shows Normal Thickness of Case as Developed Near Rolled Surface of Bar and at Right Angles to the Grain. (2) Area Similar to 1, Except Formed in Metal More Remote From Rolled Skin. (3) Shows Area of a Case Similar to that of 2, Except that its Thickness is Developed in a Direction Parallel with the Rolled Grain of the Bar. (4) Shows the Area of Case 20 Times as Thick as its Actual Thickness.

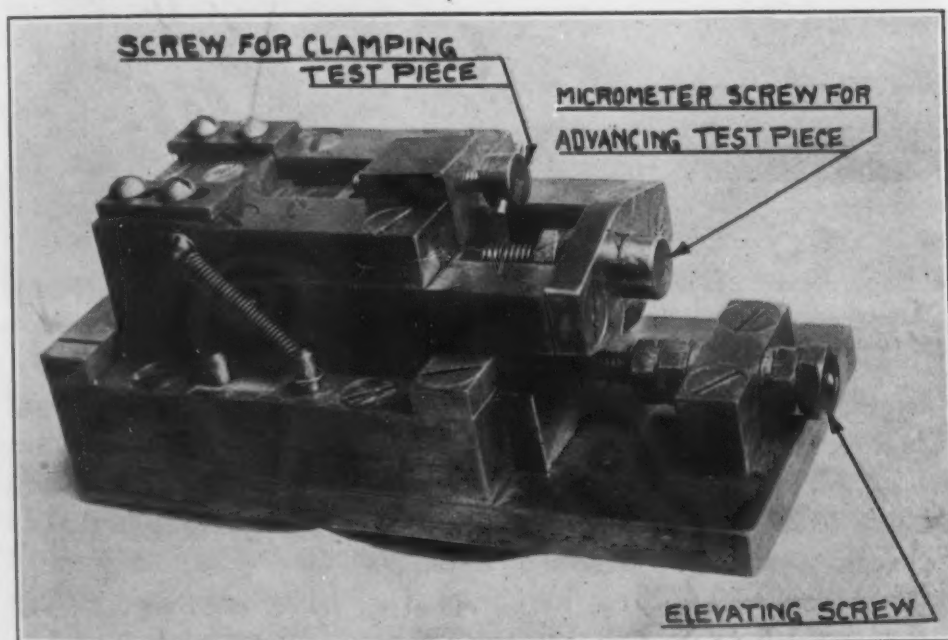


Fig. 11—Close-up Photograph of Testing Fixture for Use on the Vickers Hardness Tester.

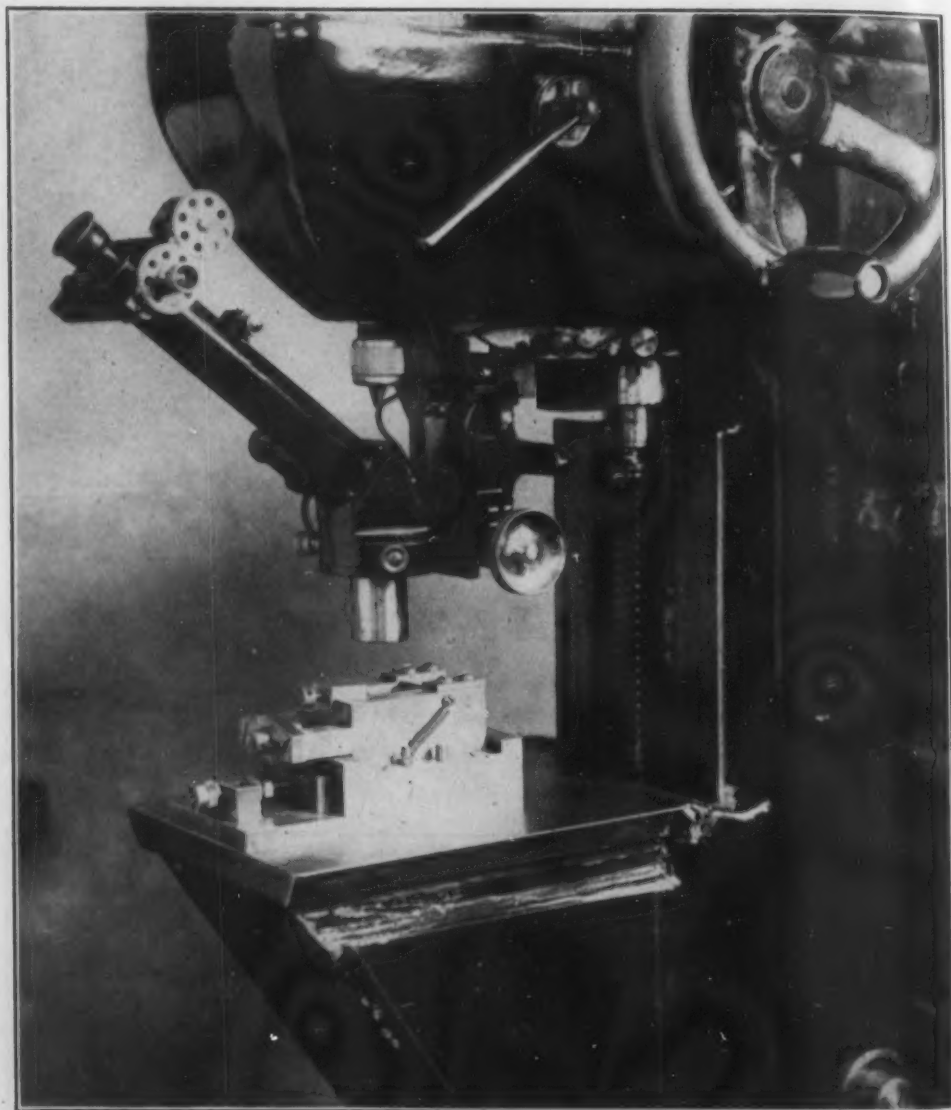


Fig. 12—Close-up Photograph of Testing Table of the Vickers Hardness Tester with Specimen Fixture in Position.

the case. At 1 we see the normal thickness of the case as developed near the rolled surface of the bar and at right angles to the rolled grain. At 2 we see a similar case except formed in metal more remote from the rolled skin. At 3 we see a case similar to that at 2 except that its thickness is developed in a direction parallel with the rolled grain of the bar, and at 4 we see a case twenty times as thick as its actual normal thickness.

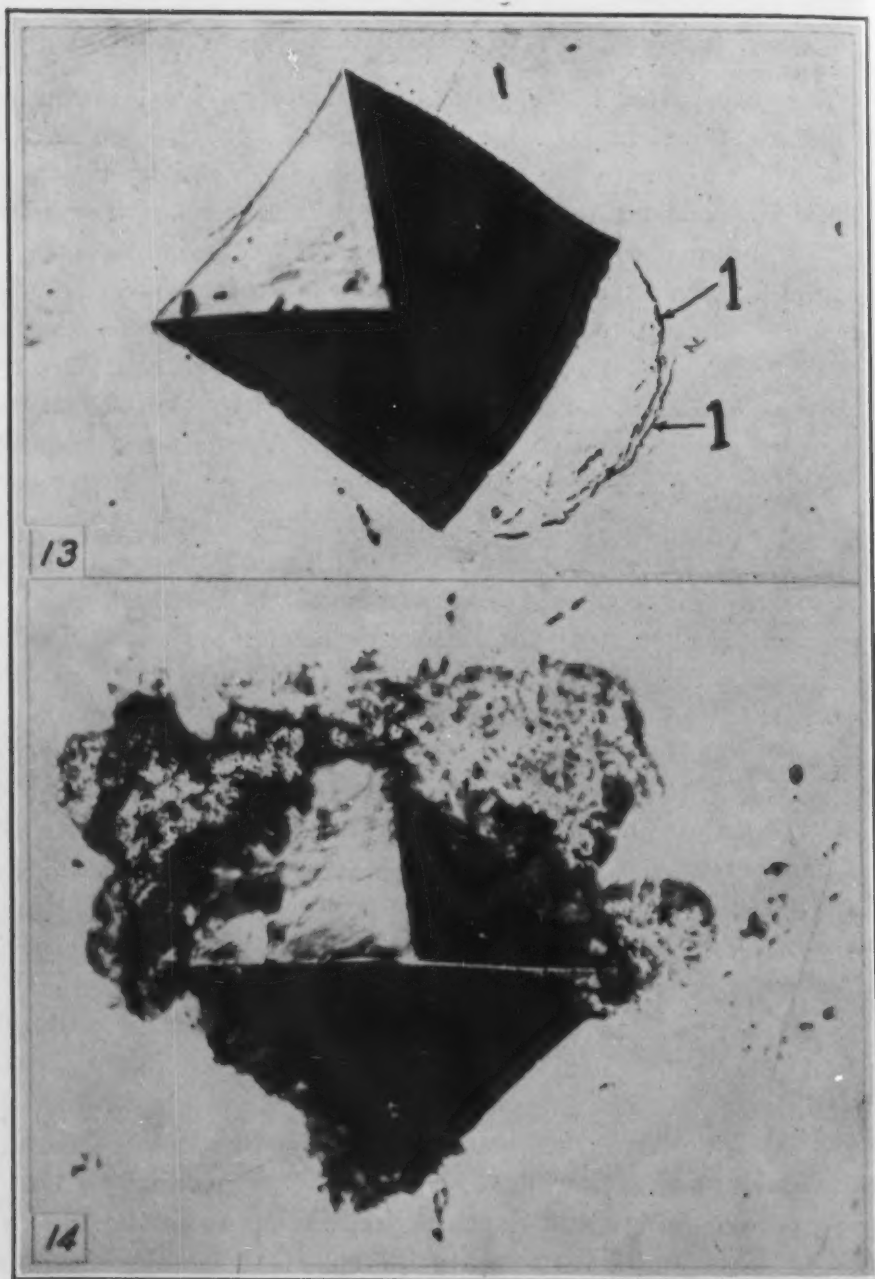
TESTING FIXTURE

The piece after taper grinding is clamped hard in the testing fixture shown in Fig. 11. This fixture contains an elevating wedge which bears to the Vickers machine the same relation that the fine focus bears to a metallurgical microscope. The fixture is firmly clamped to the platen of the Vickers machine as shown in Fig. 12. The fixture carries the test piece in a position which brings the surface to be explored parallel to the platen of the machine. The platen of the machine is then elevated to approximate location and the sample is then elevated by the wedge screw until a piece of paper is lightly caught between the test piece and the diamond point. The fixture also contains a micrometer screw which permits the advance of the test piece relative to the diamond. The test piece is set so that the diamond registers with the outer surface of the case as close as possible to the thick end. An indentation is then made and the micrometer screw is then advanced one third of a revolution. This advances the test piece one-sixtieth of an inch. Another indentation is then made and the same advance is made between successive indentations throughout the extent of the case. After getting down to the core the indentations are placed one-twentieth of an inch apart. The platen is then lowered and the indentations are read by the microscope in the usual manner for this machine, the fixture bringing the impressions accurately into position for quick and effective reading.

From a practical standpoint there are one or two real criticisms of the Vickers machine for this work. The machine would be much improved if equipped with stronger illumination so that a large number of readings could be taken with less eye strain.

It also appears possible to redesign the machine so that it would read on the basis of depth of impression as in the Rockwell machine. This would incorporate the speed of the Rockwell with the adaptability of the Vickers and make an ideal tool for the testing of the nitrided case. A simpler alternative would appear to be found by equipping the Rockwell machine with a Vickers diamond, 10-kilogram load and a generous work platen.

Referring in more detail to the ability of the Vickers machine to give some idea of the relative ductility of nitrided cases, Fig. 13 shows a photomicrograph taken at 350 diameters magnification



Figs. 13 and 14—Photomicrograph of Vickers Hardness Tester Impressions Made on Ductile and Brittle Nitrided Cases. $\times 350$.

of a Vickers indentation in a ductile case, and Fig. 14 shows a similar photomicrograph for a brittle case.

Both of these cases are of practically the same hardness, 800 to 900 Brinell. In the first instance the case literally exploded under the gentle application of the Vickers diamond as it slowly

penetrated the case, while in the second instance, the indentation is surrounded by plastic flow in a way closely representative of the Vickers indentation in ductile steels. A casual inspection of Fig. 13 would convey the idea that plastic flow had occurred on only one side of the indentation. We did not succeed in adjusting an illumination which would show the plastic flow on all four sides in a single picture. But when the specimen was revolved under the microscope we found plastic flow in evidence on all four sides. This act of revolving the piece also proved that the curved lines 1 of Fig. 13 are in reality shadows of plastically piled up ridges. Our service life tests have convinced us that it is essential to have about as much plastic flow or ductility in the case as is indicated by Fig. 13 and that when the Vickers indentation spalls, the life of the product will be definitely inferior. Thus we have found a practical control test for nitrided products intended for wear-resistant service.

SURFACE FINISH FOR VICKERS IMPRESSION

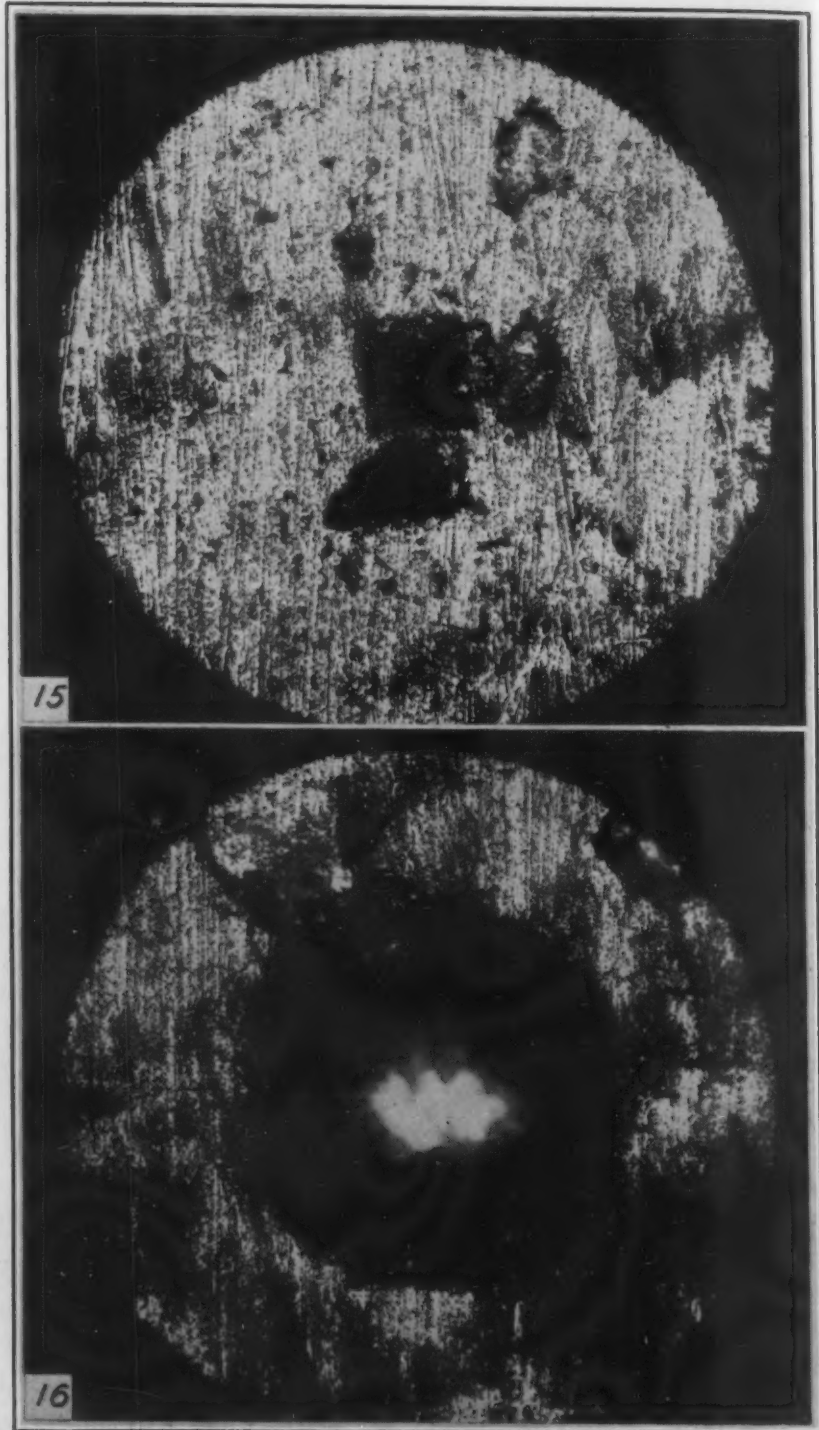
The degree of polish which is essential for using the Vickers machine is entirely dependent on the type of testing which is being done.

1. If the work is of a careful research nature, micro polish is essential, as it is impossible to make an exact measurement of the size of the indentation when heavy grinding scratches or grooves hinder the formation of definitely located corners.

2. If the work is of a production nature for the purpose of determining that the hardness falls between certain limits, the degree of polish customarily employed for Brinell testing is entirely satisfactory.

3. When the articles are smoothly ground before nitriding it is possible to omit the polishing operation entirely except when the color of the piece at the point where the reading is to be taken, is too dark. We have found it impracticable to read many impressions on unpolished nitrided surfaces for this reason. This trouble, in our judgment, is not fundamental, but is simply due to the particular illumination existing on the machine. An illuminating system can doubtless be devised which will broaden the scope of applicability of the Vickers machine.

When inspecting unpolished nitrided cases for ductility, with



Figs. 15 and 16—Photomicrographs of Indentations Made by the Vickers and Rockwell Hardness Testers. Fig. 15—Photomicrograph of the Indentation Made by the Vickers Hardness Tester on an Unpolished Ductile Nitrided Case. Fig. 16—Photomicrograph of a Rockwell C Impression, 60 Kilogram Load, Upon an Unpolished Ductile Nitrided Specimen.

the Vickers machine, it is sometimes possible to detect a brittle case with the unaided eye, as the shattered region around the indentation is silvery white and contrasts with the surrounding unruptured case face. This is not entirely safe, however, as we have found instances where the outer film of the raw nitrided surface did not appear to spall, and yet when a very light polish was applied, spalling did occur. We therefore recommend the slight polishing practice about as employed for Brinell tests.

When inspecting Vickers impressions in micro polished surfaces we have found that a certain amount of training of the eye

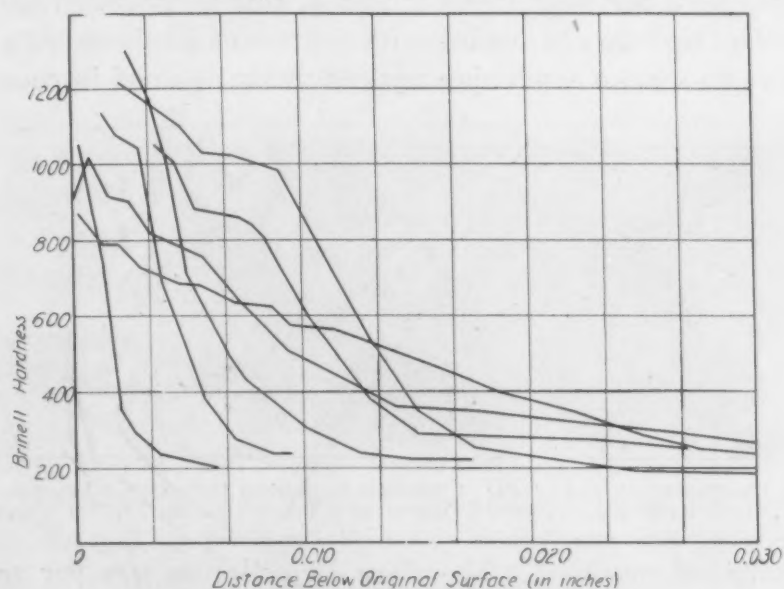


Fig. 17—Types of Hardness Penetration Curves.

is necessary to differentiate between the appearance of a spall and that of plastic flow. We found, after examining a few samples that were questionable, using the metallurgical microscope with better illumination and higher magnification, that we could learn to tell the difference more reliably. (Figs. 15 and 16).

HARDNESS PENETRATION CHARACTERISTIC CURVES

Fig. 17 shows a family of characteristic curves plotted from Vickers readings. It would be outside the scope of this paper to discuss how the various characteristics are imparted to the case. The point that we wish to emphasize is that regardless of the hardness or rate of tapering off of hardness, the Vickers diamond in-

denter hardness tester used in the manner which we have described has proven its adequacy.

ACCURACY OF VICKERS READINGS

Some of our friends whose statements we have learned to listen to with respect have expressed a doubt as to the accuracy of the Vickers readings on extremely hard surfaces. We have not regarded possible error in translation into Brinell numbers as of sufficient importance at this stage of our investigations, to warrant our making a thorough investigation of this question. This is due to the fact that we are dealing with degrees of hardness with which we have no service experience outside of that gained in connection



Fig. 18—Macrograph of a Cluster of Hardness Impressions Made with Scleroscope, Brinell, Rockwell, Herbert and Sapphire Scratch Testers on a Polished Brittle Nitrided Case.

with nitrided products. Therefore Brinell numbers per se give us no insight into logical life expectations. We are interested at present in relative hardness coupled with a measure of ductility. The interpretation of Vickers readings which indicate ductility, in terms of the results of service, will build up a meaning for these readings.

Stability of Vickers Diamond. When we started to use the Vickers machine we had serious doubt as to the ability of the diamond point to stand up for any long period against the nitrided case. The extent to which this has been checked is covered by the statement that after we had made 1500 indentations in nitrided cases at the laboratory of the Timken Detroit Axle Works, we examined the first and the last impressions on the metallurgical microscope. We found that the best revelation was secured by a magnification of 500 diameters. The focus was carried from the

surface slowly down to the point, and as far as we could determine there had been no change in the shape of the diamond.

PRODUCTION TESTS

In a great many heat treating plants with which we are acquainted, it is current practice to take one or more Brinell tests on every piece after heat treatment. If this is economic on the old established art of heat treating, and we are of the school which holds that for many important parts this is true, how much more essential it becomes in the new art of nitriding. We are convinced that unless some logical 100 per cent test is applied to important nitrided products, there is a real chance of enough scattered failures occurring to unduly discredit the nitrided product. We further believe that in particularly vital heats good practice will call for the inclusion in the furnace of test pieces to be explored for hardness and penetration. When this is done those responsible for production will have thoroughly reliable assurance of the quality of their product.

CONCLUSION

Summarizing our findings, it is utterly essential to test nitrided steel products in a thorough manner to forestall service failures, and the Vickers diamond indenter hardness tester offers one practical method for doing this. In many services involving small production, service tests can be made to feel out the propriety of nitrided steel applications, and a good degree of success can be attained. But heavy production and vital services demand effective inspection testing.

ACKNOWLEDGMENTS

Fig. 18 is a photomacrograph taken on a polished and nitrided case of clusters of all the types of hardness impressions which have been discussed above. The Vickers impressions were made at the laboratory of the Timken Detroit Axle Works through the courtesy of H. W. McQuaid, to whom we wish to make acknowledgment for the most helpful co-operation. All the other impressions shown in Fig. 18 were made at the Bureau of Standards at Washington, D. C., acknowledgment being made to Messrs. Petrenko and Muchler for assistance. We also wish to acknowledge the patience and enthusiasm of Dr. V. N. Krivobok of the Carnegie Institute of

Technology in Pittsburgh, by whom the photomicrographic work was done.

DISCUSSION

Written Discussion: By A. W. Machlett, American Gas Furnace Co., Elizabeth, N. J.

Mr. Eaton is to be complimented on the care and completeness with which he has outlined the desirable information on nitrogenized cases. It is at once evident that he has studied the subject very carefully. The results which these tests have shown as to the best means for measuring the hardness of nitrogenized cases will be of considerable value in the further development and application of this new method of casing steel.

The value of accurate data on nitrogenizing steels and nitrogen cases cannot be overestimated. Naturally, it will be of greatest value on those steels which give promise of having a commercial application.

We are quite certain that Mr. Eaton has not or will not lose sight of this fact and that he will, furthermore, parallel the hardness tests with actual service and breakdown tests of a character which will suggest themselves as being most directly in line with the possible commercial application of the steel.

In the writer's opinion and in the opinion of others of our organization who have been in close touch with the work which we have been doing along these lines, an example of one of the attractive applications for nitrogen cased steel is the piston pin. Without a doubt the information which would be of greatest value in connection with this application would be breakdown tests in which a nitrogenized case was run in various types of bearings as outlined under the "Coefficient of Friction" in Table II of Mr. Eaton's paper.

I hope that such tests can be conducted at an early date if they have not previously been made and shall be greatly interested in the results secured.

We have convinced ourselves that steel of a suitable character when nitrogenized is infinitely harder than steel heat processed in any other way, but we have not gone so elaborately into the phase of hardness determination as has Mr. Eaton. Our activities have been directed more particularly to the future developments of the process of nitrogenizing and an endeavor to determine or help to determine upon the most satisfactory steel for nitrogenizing, having due regard for the function of the article to be processed. For instance, whether the chief requirement be resistance to corrosion or wear, or a combination of both, etc.

Written Discussion: By V. O. Homerberg, Massachusetts Institute of Technology, Cambridge, Mass.

I wish that the author could have given the results of tests as outlined in Table II. Such data would furnish important information as to the characteristics of nitrided cases.

I am quite in agreement with the remarks concerning the applicability of the various hardness testing machines to the study of nitrided cases. The Brinell machine, using a steel ball, is obviously unsuitable for the

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purpose, and the scleroscope is prone to produce chipping, thereby giving a low reading. I have been unable to obtain satisfactory results with the scratch method, since the scratch is narrow, curves considerably, and the edges are difficult to determine accurately. A possibility in its use might involve the projection of the image of the scratch onto a screen, so as to obtain considerable enlargement.

The Rockwell tester with the full load does not give satisfactory results. I believe, however, that it can be rendered highly satisfactory by using a lighter load and a diamond similar to the one used in the Vickers machine, provided that the diamond cone is proved unsatisfactory for distinguishing the differences between tough and brittle nitrided cases.

The remarks concerning the applicability of the Herbert pendulum and of the Vickers tester are in accord with my observations.

The photomicrographs, Figs. 3 and 4, showing the Rockwell "C" impressions in a ductile and in a brittle nitrided case, respectively, indicate that the hardness of the former is far less than in the latter, or that the case is shallow, so that it has been depressed into the core. I am of the opinion that a case which does not show any more chipping than is indicated in Fig. 4 will be found entirely suitable for most of the intended uses of nitrided cases.

It is unfortunate that the author has not included photomicrographs of the microstructures of the various nitrided cases. The conditions of nitriding may be such as to obtain a grain boundary structure closely resembling the iron carbide network often obtained in the outermost zone of a carburized steel. It is obvious that such a structure will impart brittleness to the case.

I am in complete agreement with the recommendation that test pieces should be included in the container whenever important lots of material are being nitrided and that these pieces should be examined as to hardness and the depth of penetration, as well as to determine whether or not brittleness is present in the case. The inclusion of a notched specimen and its subsequent fracture will impart a great deal of information as to depth and properties of the case.

To reiterate an early statement, I hope that the author will be able to publish in the near future the results of the tests as outlined in Table II.

Written Discussion: By V. T. Malcolm, metallurgist, Chapman Valve Company, Indian Orchard, Mass.

We have read with considerable interest the contribution by Mr. Eaton on the "Approximation of Certain Physical Characteristics of Nitrided Steel Cases," and quite agree with him that there is at the present time no definite means of determining the true method of testing various physical characteristics as brought forward by his seven questions.

In order to discuss this subject intelligently it is first necessary to determine, what is hardness. The definition of hardness that will correspond to any physical value is a definition yet to be found. In the various methods that are used for the measurement of hardness, we believe,

that there is at the present time no knowledge of what is really being measured, and these methods only allow for certain comparison without tying up to any certain physical properties.

The scleroscope, Rockwell, Brinell, Herbert, scratch, Vickers,—all have scales obtained by different methods and, as anyone knows who is engaged in testing the hardness of materials, will find that by the use of these different methods they frequently show no definite relation to each other, and from this we may assume that there can be no correlation of the definition of hardness as applied to the different methods of test.

These differences have considerable bearing on the physical properties of the material, and it is a well known fact that certain materials that show a definite hardness that is supposed to be well within machinability of the product are not readily machinable, whereas, in other cases they may show hardness beyond the range of machinability, yet machine with ease.

For instance, in the manufacture of high chromium-nickel steels, Brinell hardness numbers rarely run over 200, which is well within the machining range; yet, due to the great toughness of this material, it is not possible to drill it without drills being somewhat off center and at much slower speeds than used in the case of ordinary carbon steels, approximating 350 Brinell hardness. Again, the same applies to certain grades of tool steel which probably have a Brinell of 160 and are not readily machinable, yet, after these steels have been treated to a Brinell hardness of 220-240 they are readily machinable. The entire solution being in the change of the structure in the steel, and while giving greater Brinell hardness, at the same time increases machinability.

Again, considerable difference in the hardness is found when they measure only the outer layers or whether they measure deeply into the material tested.

The writer, during the past few years, has gone over various papers presented on hardness and hardness testing, and believes that the best definition of what hardness is, has been offered by R. Esnault Pelterie,¹ in which he states, "By hardness is meant that property of mechanical resistance that is possessed by the outer layer of solid bodies."

"It is now well known that bodies in thin layers have properties that differ widely from those they possess when they have considerable thickness, and their mechanical properties obey this law in the same manner as do their electrical, optical or magnetic properties. When a layer of a given body has a thickness of less than 50 $\mu\mu$, the usual properties begin to be modified; for still thinner layers there is still greater change and the bi-molecular or mono-molecular layers of liquids or of gases no longer have the ordinary properties of liquid or gases and they adhere to solids with a strength that was previously unsuspected."

"For solids of appreciable thickness the outer layer presents a phenomenon similar to the surface tension of liquids except that the forces acting are very much greater."

¹"British Section of La Societe des Ingenieurs Civils de France."

²"Gesammelte Werke," Vol. I, Ueber die Berührung fester elastischer Körper, pp. 155 et seq.

Further, Hertz² formulated a theory of change of form of two bodies of any shape in contact, which is based entirely on the general equation of elasticity and of Hooke's Law. For this reason, the definition of hardness so found is as nearly absolute as possible in character. Pelterie states, that Hertz in establishing his theory starts with the following assumptions:

Firstly; Forces effecting volume are zero at all points in both bodies. This means that the gravitational forces may be considered as negligible in comparison with the mechanical forces exerted.

"Secondly; The changes of form are very small and, consequently, we are justified in using the formulæ of the theory of elasticity.

"Thirdly; The displacements are only depressions about the positions of equilibrium.

"Fourthly; In consequence of the small area assumed to be in contact, the total forces pressing the two bodies together is equal to the sum of the reactions, which are almost parallel to each other and normal to the common plane tangent to both bodies. The tangential forces are, therefore, equal to zero."

"These premises appear to be as free as possible from arbitrary terms and it would appear difficult a priori to conceive any others."

As this paper by Pelterie particularly refers to the hardness investigation of nitrided ball thrust bearings and as the work of nitriding was carried out by Messrs. Aubert and Duval (holders of the Fry patents) at the suggestion of Dr. Guillet, it may be to the point in discussing what the definition of what Hertzian hardness is.

Hertz defined hardness as being the pressure existing at the center of the surface of contact at the moment when permanent deformation began to take place. The problem, therefore, resolved itself into an experimental determination of the precise moment at which this permanent deformation begins.

Hertz has limited his measurements to transparent bodies in the form of a portion of a sphere pressed against a plane and observed the diameter of the circle of contact by the interference rings seen throughout the plate. The commencement of permanent deformation was shown by a crack in one of the two compressed bodies. This crack always occurred in the plane, showing that this reached its elastic limit before the sphere.

Hertz, therefore, called the "hardness of a body" the pressure in kilograms per square millimeter at the center of the circle of contact and formulated an equation corresponding to the total load at which the first crack appeared. Pelterie further developed this method, and in his paper gives a complete discussion of the apparatus and methods for the measurement of the Hertzian hardness with a number of formulas, tables and graphs. This method certainly appeals to the writer as to the measurement of nitrided cases more than any of the used methods at the present time.

With reference to the second question, "How thick is the case of nitrided steel?" This is apparently a simple matter, as bars 15 millimeters in diameter, notched in the center, are placed at various points throughout

the material being treated, and after treatment these notched bars are broken and depth of case examined.

In regard to question three—a small bar 10 millimeters square is placed in the load and then taper-ground from one end to the other, being taper-ground in such a manner that it starts with only 0.001 under the skin to a maximum of 0.050, and measurements are made along the bar that has been ground to correspond with this thickness.

In regard to the fourth question, "Is the case absolutely brittle?" I would state that in the tons of work that has been nitrided under the writer's supervision, he is yet to find any brittleness of the case. This, however, must not be construed to mean that nitriding does not impart brittleness; it does, unless certain precautions are taken. This discussion brings us into the fifth question.

With regard to whether different treatments produce varying shades of brittleness, from our experience I would answer this question by saying different treatments produce varying shades of brittleness, and it is necessary to determine the correct treatment for the work at hand.

I may quote at this time that one of the producers of this material with whom the writer is associated, has nitrided hundreds of small gears. These gears must show no brittleness, and I would say to my knowledge, none of these gears have shown brittleness after the nitriding treatment, yet the writer had 50 of these gears treated at another plant and they were so brittle that the simple packing of these gears together in a bag for shipment spalled the teeth.

I may say at this time that these gears were machined exactly to size before the nitriding treatment and were exactly the same size after this treatment, whereas, the gears that were treated at another location and which spalled were very badly warped, showing the treatment caused the trouble.

It is our policy in connection with brittleness to put test bars with each load to be treated and to bend these test bars on a vise after treatment, to determine the brittleness or ductility of the case.

As an example of the lack of distortion and brittleness in the work that we are producing, I would like to cite one instance of what may be considered a severe test. In discussing the use of nitrided steel for valve trim with certain power plant engineers we found that the engineers were somewhat skeptical as to the ability of a nitrided steel to do what was claimed for it and it was suggested that they be allowed to test several rings by their own method, which was readily agreed to.

One ring was taken and placed in a furnace where it was treated until it had reached a dull red. The furnace was then shut off and allowed to cool; the ring was then taken out and examined for hardness and warpage. The ring showed no loss in hardness over the original hardness and when placed on a surface plate with prussian blue, the maximum warpage was 0.0004 inch. This ring was 6 inches in diameter and $\frac{1}{2}$ inch thick.

The second test consisted of heating one-half of the ring to a dull red and plunging into cold water and then placed on a surface plate in

the same manner, and the maximum distortion was found to be 0.0007 inch.

In the production of nitrided cases, and of which we are probably the largest producers in the country, our valves are assembled and fitted before the nitriding operation, and we find that very little grinding has to be done in order to true up the surface, and it must be remembered at this time that some of these valves must withstand 5,000 pounds hydrostatic pressure without any signs of leakage between the two nitrided surfaces.

One of the most severe conditions that can be applied to nitrided steel is the operation of valves at temperatures in the neighborhood of 900 degrees Fahr. and the opening and closing of these valves under unbalanced pressure.

The seizing and galling of seat rings and disks in the operation of steam power plant valves has been of considerable importance to the power plant engineers because valve seats gall and seize, with the result that after operation they are not water or steam tight.

A certain test was made in one of our large steam stations in which valves were trimmed with Monel metal, with Monel metal against stainless iron, and with stainless iron, and the maximum number of openings and closings of these valves without seizing at an unbalanced pressure of 400 pounds on one side and a temperature of 782 degrees Fahr. was twenty-five times. With the nitrided steel, we opened and closed a similar valve under the same conditions two hundred times without a single mark or scratch on the seat.

Questions six and seven refer to commercial production and the necessity of inspection. We have already stated that certain impact bars, taper bars, bars for bending, are placed in loads of material to be nitrided. As there are a number of bars of each type throughout the load it is fair to assume that the load has been correctly treated if the bars have been properly nitrided from the different sections of the nitriding furnace.

However, in our case, after completion of these tests each piece of work is gone over separately with special testing files and a very light rub taken on sections of the work one or two inches apart, so that any soft spots that might develop in the work may be readily noted.

Destruction tests of material are also made from the various sections of the furnace, so that the ductility and depth of case may be noted in the actual work under treatment.

Adding further to this, we may say that certain test blocks $2 \times 1 \times \frac{1}{4}$ inch are made in the same manner and placed in a wear testing machine where they are rubbed together 35,000 times with no lubricant and under 100 pounds pressure and the wear noted.

In our opinion, while putting us to considerable expense and time, it is necessary to test heats of nitrided steel in this manner, regardless as to the automatic control of the temperature and the ammonia concentration.

Structure of the alloy steel to be used for nitriding is of first importance when received, as there is a tendency for this material to be somewhat abnormal.

Material that has been spheroidized will not readily harden under the nitriding treatment and material that has been decarburized is another source of difficulty, but, it may be eliminated by thorough inspection methods before the steel is put into production.

The writer wishes to congratulate Mr. Eaton on his contribution and particularly on the seven questions, because they are of first importance and unless the answer to each one of these questions has been satisfactorily worked out one should enter into the nitriding of steel particularly from a production standpoint with caution, as he is certainly bound to run up against a vast amount of difficulty.

Oral Discussion

FREDERICK FRANZ: Mr. Eaton expressed the keynote of the matter when he said, "What machine or instrument shall we use for measuring the hardness?" It seems that the object of nitriding is to obtain wear resistance, and that should be the one point in view in testing the success or the failure of the process. It is not a question of Brinell, scleroscope or cutting hardness, or of resistance to corrosion, but merely wear resistance. So, with that in view, the thing to do is to measure it (wear resistance) in contact with a rubbing member and see what the effect is. I might suggest in conducting tests that any material in contact with itself, may give different effects than in contact with some other material, and also that the long experience of watch and clock makers should not be overlooked, in that rubies, diamonds and sapphires, which are really very brittle, have proved to be the most successful bearings for the hard service, 24 hours a day and ten, twenty, and thirty years' life, expected of watches. Here is a case in which toughness is not necessarily one of the essentials of wear resisting qualities.

A. B. KINZEL: Mr. Eaton just touched on the scratch test in this paper. The scratch test has been used at the Union Carbide Laboratories in connection with the research work that we have done on this problem, and we find it a very excellent laboratory tool. We can agree entirely with Mr. Eaton, however, that it will be most out of place in the shop, certainly in its present form.

I would like to ask Mr. Eaton if he has ever tried to correlate the load at which the nitride case on a tensile test specimen breaks and forms rings with the ductility of the case. We have done a little work in that direction, and we believe there is a very distinct correlation. Moreover, it is something which is susceptible of quantitative measurement.

Another point regarding the ductility of the case. We find in transverse bars that the measurement of the deflection at the instant of fracture of the case is again a very good indication. Just how quantitative this method is, we do not know, as yet. However, I do believe that it has more potentiality of becoming quantitative than simply observing the nature of the impression under a diamond. That is a matter that will have to be worked out.

I should like to have Mr. Eaton's opinion on these subjects and to

compliment him on a decidedly practical qualitative solution of the problem.

P. A. E. ARMSTRONG: Adequate testing of the hardness of nitride cased steel or similar thin hard cases is extremely difficult. The underlying surface supports the case, therefore any penetration method of testing is reading resistance to penetration, which is the combined opposing forces of the underlying surface and the case. A soft exterior of an otherwise hard case will give a high hardness reading even by such an excellent machine as the Vickers, and if the testing is done by the Rockwell machine C scale, the hardness figure will be comparatively low, and again the soft layer on top of the otherwise hard case is not disclosed. A system of scratch testing does not record surface hardness, but, rather, the hardness of the layer underneath in the instance of a thin, soft overlaying layer. A system of testing by a rubbing method would give results which could be interpreted into degrees of hardness of the actual surface. The difficulty here is the surfaces to be rubbed together, just what shall be employed and the lubricant, if any. I should fully expect to get a very different result on a humid day from that obtained when the atmosphere was dry irrespective of the variable arising from greasy or moist fingers handling the test pieces. Nitride case hardened steels, which are supposed to be one thousand or more equivalent Brinell hardness upon their surface, are not anywhere near as hard as the figure given. This hardness figure is obtained by measuring the hardness some distance below the top surface. A specimen of nitrified case hardened nitralloy, case hardened by the usual method of subjecting it to forty hours at 1,000 degrees Fahr. in ammonia atmosphere, gave a hardness on the C scale Rockwell of 550 Brinell. Tested average readings with the 30-kilogram weight Vickers gave 750 Brinell hardness. With a 10-kilogram load, the same machine gave average tests of 1,100 Brinell. The surface of the specimen had been lightly polished off on a fine paper, so that the surface was bright, but very little had been removed from the surface. The sample had merely been rubbed by hand on a sheet of fine abrasive paper. The indentations made by the Vickers machine with a heavy and light load showed that a sizeable burr was thrown up at the surface edge of the indentation. These results clearly show that the Rockwell and the heavy load Vickers was testing the supporting properties of the underlying material or core, plus a certain amount of resistance penetration by the case. The light load test of the Vickers machine tested more of the resistance of penetration by the case than the supporting core, although the supporting core did its share to hold up the case so that the test could be made. The burr thrown up by the Vickers test with both series of weights show that the surface was sufficiently soft to be burred up, and I assume this surface hardness is less than 650 Brinell hard because a file would make a mark on the surface. To prove this conclusion a further test was conducted. Two similar samples of nitrogen-hardened nitralloy were tested. One surface was ground more than the other. Both of them produced a hardness result with 10-kilogram load on the Vickers machine of an average 1,100

Brinell in one instance, and the extra-ground one 1,200 Brinell. These samples were then tested by the Herbert cloudburst machine. The falling balls giving the maximum fall perceptibly bruised the surface of the nitrogen-hardened specimen which had been polished and not ground, and had practically no effect at all on the sample that had been ground and polished. This latter check tends to prove that the hardness indication obtained by such excellent machines as the Vickers, even with a small weight, is not a true indication of the surface hardness. These tests also tend to show that nitrogen hardened steel should be ground to remove the soft uppermost layer before being put into service, unless another system of nitrogen impregnation be employed where the surface softness can be obviated.

R. F. COHN: We have a very interesting phenomenon in the wire industry, whereby we are able to take a soft, low carbon steel wire and cut the hardest surface available. It has been a problem with us for a number of years to get a material sufficiently hard for a certain portion of our machines that will not be cut by a low carbon and apparently very soft wire.

The point that I would like to make is to endorse the previous speaker's remarks on the measurement of hardness. I believe that rubbing hardness is something that has been neglected to a considerable extent. We measure hardness by direct bearing down, but I believe there is a great deal to be done in the way of measuring hardness by running it across the surface we measure, such as a wire does as it passes over a surface.

A. H. D'ARCAMBAL: Mr. Chairman, it was interesting to hear from a previous written discussion, that one company is able to nitride parts that show a fair amount of toughness. We have not been able to attain any nitrided parts that are not brittle. Is the method used by that company a special one, or do they use special steel, or just how do they obtain parts that have been subjected to the nitriding process and are still not brittle?

R. H. HOBROCK: I would like to ask Mr. Eaton whether he has made any of these tests on samples that were made in the vacuum furnace. It seems to me if some of this aluminum is in there as an oxide, it may very greatly affect the inner granular coatings,—the absolute cohesion of the material. That might in some cases account for the fact that some of the steels after being given the treatment were very brittle and chipped easily and others with the same sort of treatment were quite all right. I would like to know whether anyone has done anything with the vacuum furnace on this alloy. It seems to me that is quite important.

G. M. EATON: Referring to Mr. Machlett's suggestion that nitriding of a piston ring would be a good thing, and asking whether it had been done, Leon Guillet has reported the nitriding of the bore of the cylinders of an aircraft engine and of the piston rings. He ran it in competitive tests for 100 hours against his standard product. I do not remember the wear, but I can give you this indication. The oil consumption at the beginning of the test was at the rate of four units, whatever they are, and at the end of the test, twelve units, with the standard engine. With the nitrided surfaces the oil consumption at the beginning was four units and at the end of 100 hours it was four units.

Professor Homerberg asked about why the Rockwell was not just as good as the Vickers.

I think the ideal machine would be something reading a la Rockwell, so you get a quick reading for the hardness measurement, have the square pyramid diamond and the dial reading and get it quickly, but I think that the impression should then be inspected under the microscope to see whether this plastic flow exists.

Professor Homerberg mentioned that in the paper there are two Rockwell impressions shown. If you will notice, underneath there in the paper it states that the small is the 60-kilogram loading and the large is the 150-kilogram loading. The steels are the same, in fact, the same pieces are used for the Vickers impression, so the fine cracks as produced by the light Rockwell loading are on the same steel which exploded under the Vickers, the same pieces.

Mr. Malcolm mentioned Hooke's Law in connection with his discussion. We have cast about a good deal to find out what the modulus of elasticity of the nitrided case is and the only way that we have been able to think of is making a thin tube, so thin that it will be all case, and then pulling that as a test piece. We do not know, it may not show anything. If it does not, I do not see how to attack the problem, because we have found that sharp points, nitrided by the gas method, regardless of any condition we have been able to establish in the steel, do not behave well, the points have come off in shipment packed in cotton, and we temporarily abandoned the gas nitriding of sharp points. We have plenty of other things to work on. We have quite a lot of pieces that we caught part way through, and just because we were interested in other things, we stopped trying to handle sharp edges and sharp points by the gas process. We have other nitriding processes where we can nitride sharp points better. At present they look a little more expensive, and we are focusing on the gas because we want the cheapest thing we can get.

It has been our experience that breaking the sample and observing the case does not give the true depth of the case, because we can always find a deeper case by exploring with the Vickers machine. I agree with everything that has been said about the Vickers machine. The reading as you get down close to the case is not honest, it is just a thin skin supported by something softer, but the fact remains that the Vickers exploration reveals a deeper case than is visually observable in our experience, either by taper grinding and etching or by the microscope.

On wear resistance, rubbing hardness, please show us a way to do it. We are just hungry for it. I am absolutely and utterly from Missouri on every kind of wear test. In my business I show people wear tests, showing the wonderful results of molybdenum in certain alloys, but I say to them, "We did it this way and on this test it means this, but in service it does not mean a thing until you have done it and proved it."

In connection with pulling test pieces and observing the cracking of the cases, as shown in Table II in the paper, we laid it out in our program. In connection with this program that we laid out, if we could only have 10 highly-trained investigators and work them 16 hours a day

for 10 years, we think we could make a pretty good hole in that program. That is one of the things we have not yet done. But instead of taking the cases visually observable, our plan, when we get to it, involves pulling a series of samples by rather finely graduated steps and then putting them under corrosion to bring out a finer crack than we can get under the microscope. I am a little dubious of our being able to see the crack when it first comes. I have never been able to find fatigue cracks under the microscope, even when I knew they were there and proved it by breaking the pieces afterwards. In fact, I have found fatigue cracks three-quarters of an inch deep in locomotive axles that I could not find with a microscope. I put the axle under the press on suspicion and broke it and found the cracks.

Wire rubbing sounds very interesting. You know, in stone quarries that is the way they cut marble. They run a wire 300 feet long and cut right down through the marble. I had a little problem of cutting an Arkansas stone. I tried it on every cutting wheel I could get in my own little laboratory and I could not cut it. I finally took a soft annealed wire and cut it right in two, with water as a lubricant.

The vacuum furnace steel sounds interesting. I would like to see it tried. We have done nothing with it.

A. H. D'ARCAMBAL: Mr. Chairman, I asked a question a little while ago that was not answered. We know that considerable progress has been made during the past year in nitriding steels, better steel having been introduced for this purpose, and now we learn that we can produce the proper depth of case in a shorter time. But what we are interested in knowing is whether the case as produced today in the proper manner is practically as tough as the case on the ordinary case-hardened steel. I would like Dr. Homerberg or any of you gentlemen to answer that question. That is something we are all interested in, namely, toughness of the case in nitrided steels.

V. O. HOMERBERG: Mr. Eaton points out, that with the Vickers machine that he really determines whether or not he has toughness in a case as well as hardening.

My own opinion is, that inasmuch as you have so much greater hardness, going above 1000 Brinell in most cases, I would hardly expect it to be as tough as the ordinary case-hardened material.

A. H. D'ARCAMBAL: One reason, Professor Homerberg, I asked that question was because of the written discussion from a representative of the Chapman Valve Company, in which he stated they were nitriding gears and other parts with resultant toughness, whereas in the case of other people treating gears by the nitriding process, they were so brittle that they cracked in shipment. Now, is there such a difference in treatment that in one plant a very tough nitrided gear is produced, whereas in other plants a gear so brittle that it will break with hardly any handling is the result.

V. O. HOMERBERG: It is my opinion that too little attention is paid to the amount of dissociation of ammonia. I know that from some practical experience where this work is being done. But where the dissociation of ammonia is kept around thirty per cent, and, furthermore, where you make

absolutely sure there is no nitriding to any degree of the decarburized surface, you will get away from that embrittlement and that tendency to chip. Where you look out for the question of freedom from decarburization and keep your dissociation of the ammonia around thirty per cent, you will get away from that to a great extent.

MR. JUPPENLATZ: Mr. Chairman, I might add to his remarks that in the further discussion of the paper, we explain some of the methods of testing the ductility of the case and the hardness of the case, and in that we found that the Vickers machine was probably the only method of testing the hardness of the case. In addition to that, we place in each load bend bars and impact bars, by which method we can measure the ductility of the case. We also make tests of each individual piece in several places, that is, with a file, in order to check up in a rough manner the hardness of the material. Occasionally there are some soft spots found, but that is becoming less and less frequent on each nitriding load.

Regarding those gears that I mentioned, we found that on the gears that were nitrided at an outside place, they were considerably more brittle than those that we are now producing. As a matter of fact, from the practical tests and from hardness tests, we find that there is no spalling on the gears that we are making today as compared with those that were previously received. Previously, even a slight banging together of those gears, such as they would have received in shipment, caused considerable spalling, which apparently does not seem to be occurring today.

I might add that the structure of the material has a great deal to do with the toughness and ductility of the case. Some of those steels are quite likely to be abnormal and have large grain size unless proper treatment has been given to the steel before nitriding.

A. H. D'ARCAMBAL: In other words, you check the structure before you accept the material for nitriding.

MR. JUPPENLATZ: That has been done in every case. I would like to give more information on the method of our nitriding and the operation of our furnaces, but I think at a later date Mr. Malcolm will present a paper on that process.

CHROMIUM-COPPER STEELS AS POSSIBLE CORROSION RESISTING FERROUS ALLOYS

BY B. D. SAKLATWALLA AND ALBERT W. DEMMLER

Abstract

The data presented in this paper are the results of experimental laboratory work in a study of the merits of a chromium-copper combination in steel. The study was restricted to commercial and practical ranges of the two elements. The main purpose of the study was the development of commercial steels of high physical properties combined with fair corrosion resistance and producible at a commercially reasonable cost. In viewing the results, it should be borne in mind that not all the samples under investigation were from commercially produced heats in large tonnage. The results obtained are sufficient indication of the trend of qualifications of the material and should serve as stimulus for further work on a commercial scale.

THE addition of copper to chromium steels imparts marked characteristics to them altering their resistive properties to various corrosive influences, especially resistance to mineral acids, such as sulphuric, and greater resistance to scaling and deformation at higher temperatures. The composition of these steels can be divided into two distinct ranges, each useful in its own field, namely; a group containing chromium upwards of 12 per cent of the range of "stainless" steels, and the other containing chromium lower than this "stainless" range.

The properties of the high chromium range steels are well-known. The influence on these properties by the addition of copper is brought out in the experimental results presented in Table I. For the sake of comparison, plain chromium steels in the equivalent ranges are included in the tabulation; also, for comparison, some steels with nickel are included.

A paper presented before the tenth annual convention of the society, held in Philadelphia, October 8 to 12, 1928. Of the authors of the paper, who are members of the society, B. D. Saklatwalla is vice-president and Albert W. Demmler is metallurgist with the Vanadium Corporation of America, at Bridgeville, Pa. Manuscript received July 9, 1928.

A comparison of the two groups designated by "S" and "14" under column "Test" in Table I shows that the only difference in compositions, aside from the slight manganese and chromium content differences, is the presence of copper. The Brinell survey shows the hardening influence of this element distinctly. On the other hand, a comparison of the groups designated as "3" and "28" might be misleading due to wide differences in carbon and chromium, aside from the copper content in the "3" group.

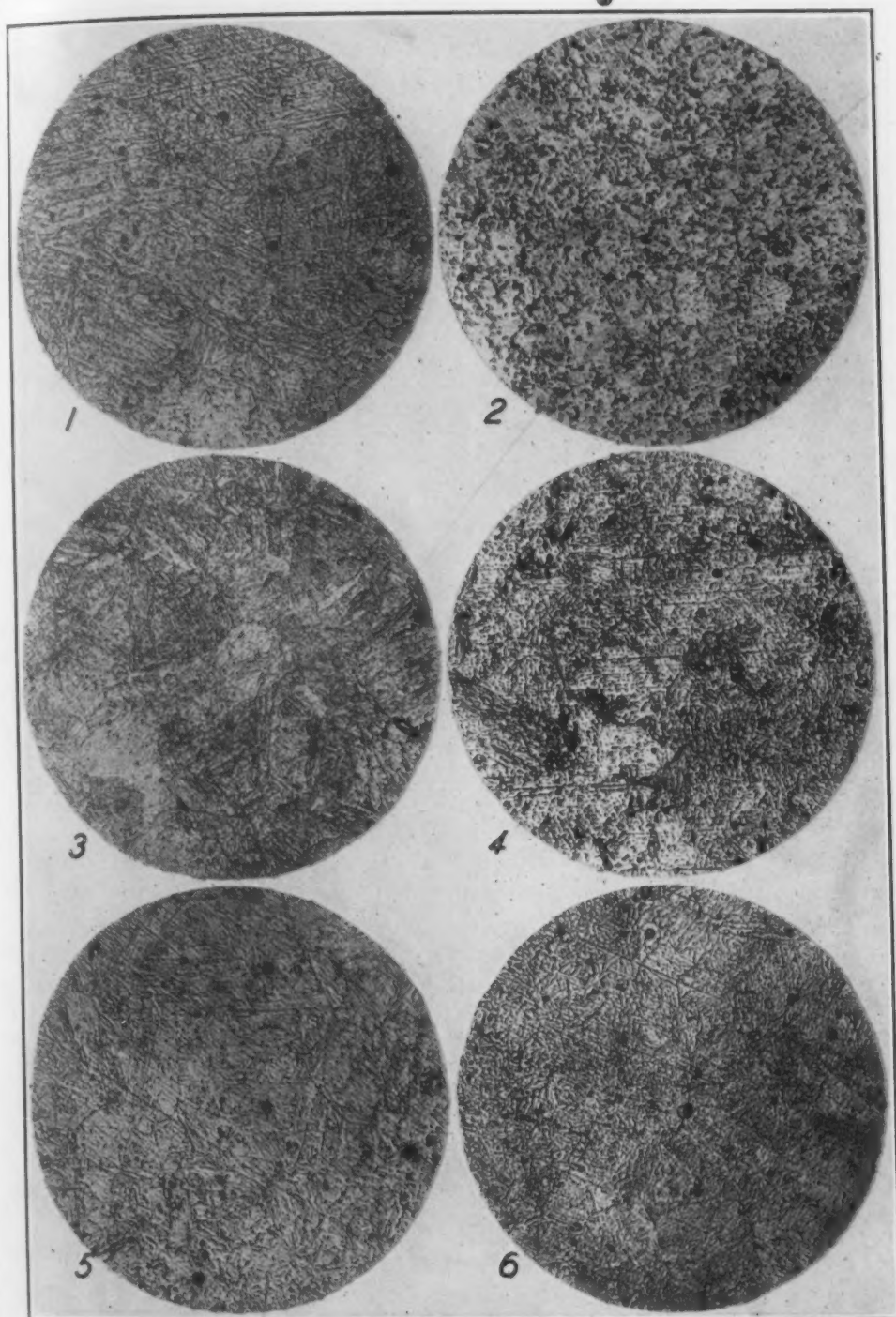
In the annealed state, both types S and 14 show considerable carbide under the microscope. Photomicrographs Figs. 1 and 2 represent S_1 and 14_1 respectively, etched with aqua regia and glycerine. Considerable more of the needle structure is present in S_1 than in 14_1 .

In the S_2 , 14_2 , S_3 and 14_3 sections shown respectively in Figs. 3, 4, 5, and 6, the carbide is rather completely in solution and there is little to choose from the standpoint of structure.

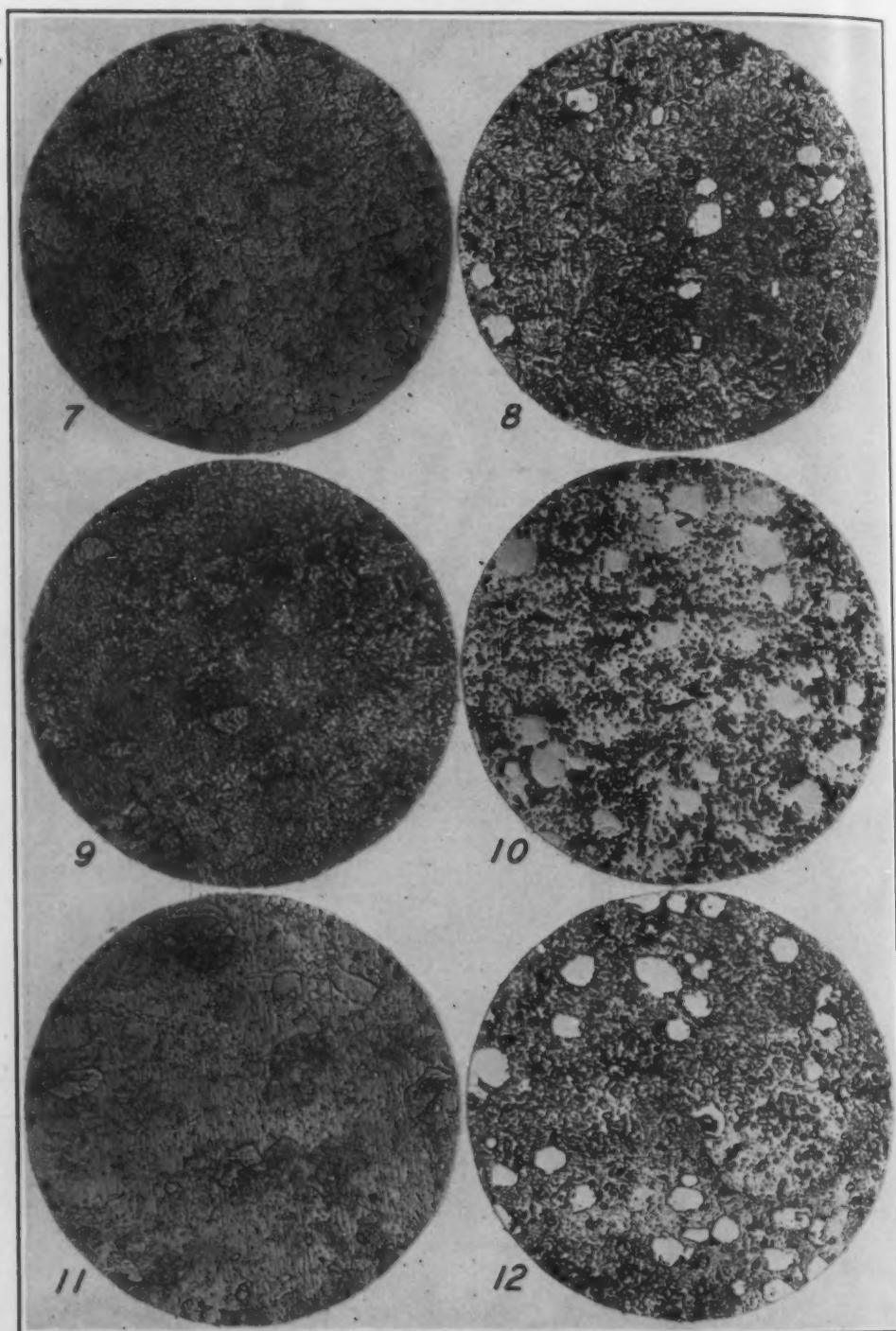
In the material of 20 to 28 per cent chromium content, the carbide is visible for all treatments. The difference between the "3" series and the "28" series is very outstanding. Figs. 7, 9 and 11 are 3_1 , 3_2 and 3_3 ; while Figs. 8, 10 and 12 are 28_1 , 28_2 , 28_3 . It appears to the authors that the structural trend to be seen in Figs. 9 and 11 may be ascribable to alpha iron. This trend is marked in the Figs of the "28" series. The "3" series is so different in carbon, chromium and copper from the "28" series, that it is not possible to ascribe the trend of the latter series to any one difference in composition, because the lower carbon is favorable to it as well as the higher chromium, aside from any copper influence. The imputation of the structural difference to the presence of alpha iron is undoubtedly controversial.

From the standpoint of physical properties, the copper-bearing chromium steels in the "stainless" range containing about 12 to 14 per cent chromium are undoubtedly preferable to those containing 20 per cent chromium and over. The increased chromium content over the usual 12 to 14 per cent, owing to increased cost, would therefore be justifiable only in particular applications, such as need for resistance to scaling.

Table I carries also comparative tabulation of the results of corrosion tests in various acids and also a test of behavior toward oxygen water. This test has only a comparative value and is used



Figs. 1, 3 and 5—Photomicrographs of High Chromium-Copper Steels, S_1 , S_2 , and S_3 respectively. (1) As Received. (3) Quenched at 1750 Degrees Fahr. in Oil and Tempered at 800 Degrees Fahr. (5) Quenched at 1750 Degrees Fahr. in Oil and Tempered at 1112 Degrees Fahr. Figs. 2, 4 and 6—Photomicrographs of Rustless Chromium-Iron, Steels 14₁, 14₂ and 14₃ respectively. (2) Structure After Heating at 1575 Degrees Fahr., Furnace Cooled. (4) Quenched from 1750 Degrees Fahr. in Oil and Tempered at 800 Degrees Fahr. (6) Quenched in Oil at 1750 Degrees Fahr. and Tempered at 1112 Degrees Fahr. All Specimens Etched in Aqua Regia and Glycerine. $\times 300$.



Figs. 7, 9 and 11—Photomicrographs of High Chromium-Copper Steels, 3₁, 3₂ and 3₃ respectively. (7) As Received and Annealed. (9) Heated to 1820 Degrees Fahr. and Quenched in Water and Tempered at 800 Degrees Fahr. (11) Heated to 1820 Degrees Fahr. and Quenched in Water and Tempered at 1112 Degrees Fahr. Figs. 8, 10 and 12—Photomicrographs of High Chromium Iron, Steels 28₁, 28₂ and 28₃ respectively. (8) Heated to 1575 Degrees Fahr., and Furnace Cooled. (10) Heated to 1825 Degrees Fahr., Quenched in Water and Tempered at 800 Degrees Fahr. (12) Heated to 1825 Degrees Fahr., Quenched in Water and Tempered at 1112 Degrees Fahr. All Specimens Etched in Aqua Regia and Glycerine. $\times 300$.

on account of its greatly accelerated effect and giving some picture of the combined action of moisture and oxygen. The specimen is immersed in distilled water through which oxygen is bubbled for a 24-hour period at a regulated measured rate.

The copper-bearing chromium steels of the lower range as represented by Table II are of very great importance as they fill in a gap in rust resistive ferrous materials which is not occupied by any class of material today. The general technical merits of this group lie between the plain copper-bearing steels and "ingot" iron such as "Armco", on the one hand, and high chromium and chromium-nickel "stainless" steels and iron on the other hand. This intermediate position is obtained at a very low cost, together with the property of additional resistance to mineral acids and acid atmospheres, which property is not present in the high chromium steels in spite of their high cost. Also, chromium-copper steels of the composition in question can be manufactured by the ordinary open-hearth process at the low open-hearth melting cost and not necessitating the expenditure of electric furnace melting, as is the case with the high chromium "stainless" steels. Further, on account of the low chromium content of these steels, the ordinary cheap grades of ferrochromium can be used without unduly raising the carbon content of the finished steels. The cost of these steels will be that of ordinary open-hearth steel plus the actual cost of the chromium and copper contents, which can be easily figured by any steelmaker.

The results of physical tests obtained on various samples of different compositions are given in Table II. In this tabulation all the results as obtained are given without attempting to select them, so that a fair idea of the characteristics of the material can be obtained. These samples happen to be from small melts obtained in the laboratory and undoubtedly in commercial practice when the material is manufactured on a large scale more uniform products can be obtained, as the material will then have the benefit of the usual mill control and inspection in rolling and fabricating.

The tabulation is primarily a survey of physical and corrosion data for steels running from 0.15 to 0.50 per cent copper with chromium from 0.3 to 3.5 per cent and carbon running from under 0.10 per cent to as high as 1.25 per cent.

The low range chromium-copper steels are in five carbon groups; 0.05 to 0.1; 0.1 to 0.17; 0.17 to 0.26; 0.26 to 0.51; 0.73 to 1.27, and arranged in order of chromium content within each group.

First, a comparison of physical results will be considered. All the under 0.10 per cent carbon heats of chromium-copper steel contain 3 per cent chromium and its effect as well as that of copper, though to a lesser degree, is felt in the physical properties. These properties cover a range between the following limits.

Yield Point Lbs. per sq. in.	Ultimate Strength Lbs. per sq. in.	Elong. 2 inches Per Cent	Red. in Area Per Cent	Brinell
49,000	79,000	34	63	151
106,000	144,000	17	48	300

Upper specimen annealed. Lower specimen quenched and tempered at 900 degrees Fahr.

In the under 0.17 per cent carbon group with chromium to 1 per cent, the physical properties show the effect of the lower chromium content, ranging in the following limits:

Yield Point Lbs. per sq. in.	Ultimate Strength Lbs. per sq. in.	Elong. 2 inches Per Cent	Red. in Area Per Cent	Brinell	Izod Per Cent
42,000	50,000	35	72	100	90
60,000	76,000	26	60	165	55

Upper specimen annealed. Lower specimen quenched and tempered at 800 degrees Fahr.

With the chromium up to 3 per cent, the Brinell number increases, the tensile results are higher, but the Izod is somewhat lower. A higher quench throughout the 0.17 per cent carbon group would undoubtedly help physical properties too.

In the under 0.26 per cent carbon group (chromium 1 to 2 per cent) the physical properties range between the following limits;

Yield Point Lbs. per sq. in.	Ultimate Strength Lbs. per sq. in.	Elong. in 2 inches Per Cent	Red. in Area Per Cent	Brinell	Izod
45,000	65,000	26	60	120	90
140,000	156,000	14	45	300	4

Upper specimen annealed. Lower specimen quenched and tempered at 1000 degrees Fahr.

With the chromium up to 3 per cent, increased hardness can be expected. The low Izod of the hardened test above may be due to incomplete refinement of the steel, as notch tests are extremely sensitive to incomplete deoxidation. The higher carbon of the under 0.51 per cent carbon group increases the hardness with decreased ductility.

The remarks pertaining to corrosion tests in connection with the Table I also apply to Table II. Table III is compiled for the sake of comparison alone, especially with reference to corrosion results.

The physical properties and corrosion results are given for various heat treatments and from these data it can be seen the composition is very susceptible to heat treatment.

From the data of the various tables, it appears that the chromium-copper physical properties far surpass the plain low carbon copper physical properties and more than hold their own against any of the high alloyed corrosion resistant materials. The following remarks pertain to the corrosion results:

In the class of under 0.10 per cent carbon steels, the air-cooled condition corrodes much more than any other heat treatment.

In the next carbon group, there is no choice between treatments, and the annealed tests of the under 0.10 per cent carbon run fairly close to the results of this group, except that the low carbons are definitely better in oxygen water. It appears possible that the 3 per cent chromium tests are more sensitive to heat treatment than the lower chromium tests. Sealing results in this group run close together.

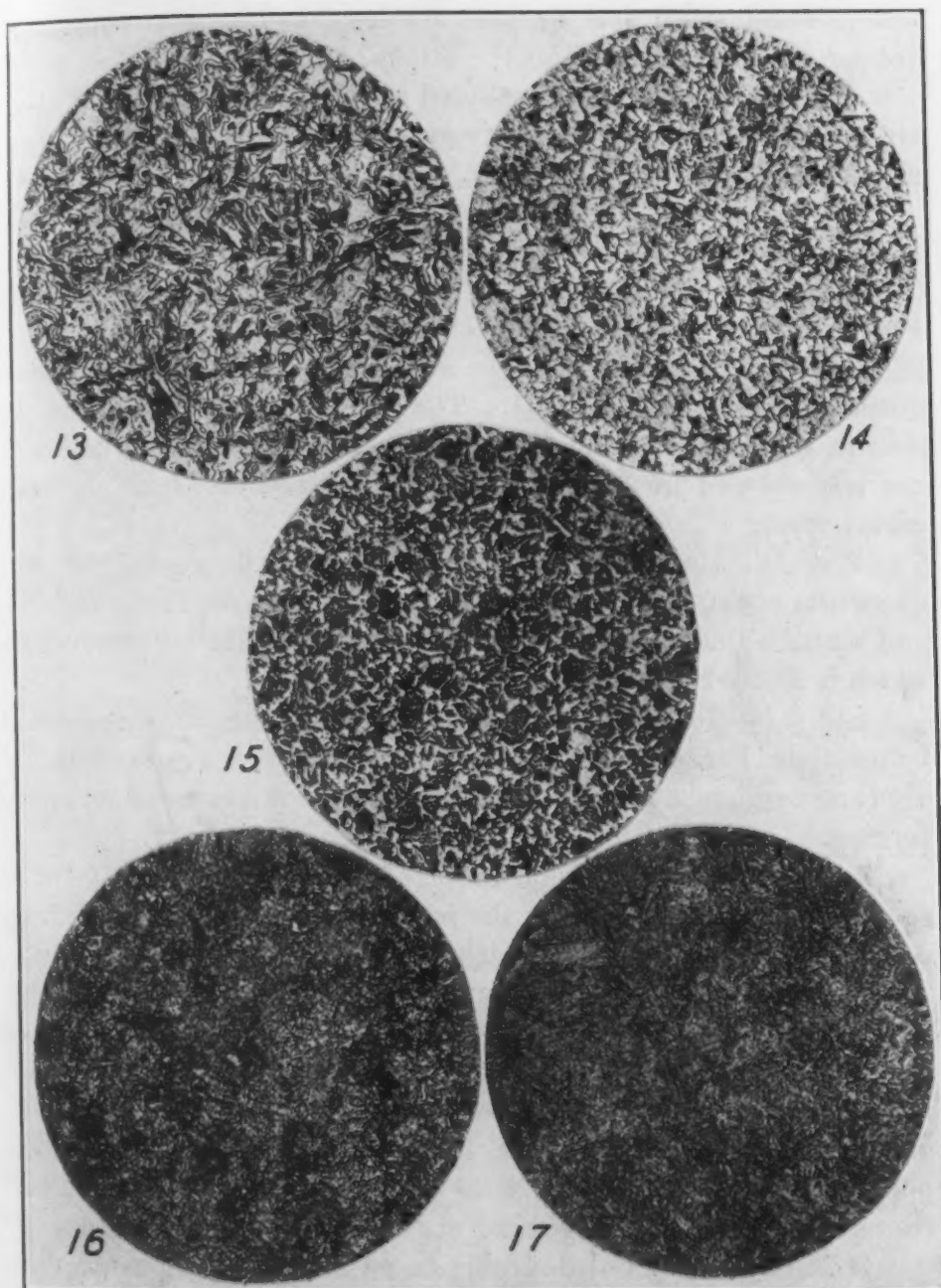
For the high carbon group in the hardened state the oxygen and water corrosion is excellent, and in the annealed state the results are also very good. Looking into oxygen water alone the low chromium-copper steels, especially the carbon groups under 0.10 per cent and the one from 0.73 to 1.27 per cent hold a very admirable position among all the corrosion-resistant materials. (See Table III for comparison).

In hydrochloric acid (5 per cent) the low chromium-copper heats run better than all but Monel metal, Resistal, and Toncan, and about the same as chromium iron. In sulphuric acid (5 per

[illegible]

Table III

Heat Test No.	Condition & Heat Treatment	Chemical Analysis							Tensile Tests			Immersion Tests					Sulphur Test			
		C	Cr	Cu	Si	Mn	Ni	Yield Point Lbs./Sq. In.	Ultimate Strength Lbs./Sq. In.	% Elong. 8 in.	% Reduc. Area	Loss H ₂ O-HCl	Loss H ₂ O-H ₂ SO ₄	Loss H ₂ O-HNO ₃	Sq. Cm.	Sq. Cm.	Grav. Loss Inch. Time			
	Mild Steel as Rolled	.14	—	—	.07	.44		32000	49400	35.0	62.0	10.5	1.6	31.6	17.4	32	95	16	162.0	6.0
	" Annealed											107	1.1	20.6	14.3	2.4	54	96	161.0	
	" Quenched											131	2.0	37.3	29.9	2.3	86	1.4	163.0	
20-2	Old Dominion Electric Steel	.14	—	—	.13	.24		36500	57500	32.0	64.0			17.1	31.5					
	Ulster Double Refined Wrought Iron	.18	—	—	.14	.03		35400	49600	31.0	50.0	6		48.0	185.0					
	Newport Copper Bearing Steel	.10	—	.30	.01	.14						8		5.0	4.4					
	Toncan "	.05	—	.30	.02	.13		33000	50000	28.0	69.0	100	6	3.0	2.5					
	ARMCO Ingot Iron	Impurities less than (14)																		10.2
	Monel ~ Copper Nickel as Rolled	.12	—	26.98	.06	1.62	67.78					10	58	46	.6	.1	.32	26.0		



Figs. 13 to 17—Photomicrographs Showing Structure Attained with Different Steels when Quenched in Oil from 1575 Degrees Fahr., and Tempered at 1000 Degrees Fahr. All Specimens Etched in 5 Per Cent Nital. $\times 150$. (13) Heat 233. (14) Heat 202. (15) Heat 191. (16) Heat 190. (17) Heat 162. For Analysis of Each of These Steels see Table II.

cent) Monel metal and Resistal again rank first with chromium-copper better than most all the others.

Photomicrographs are included showing the structure of these steels. The compositions represented by these photographs are shown in Table II.

Fig. 13, Heat 233—has the same appearance as chromium-nickel carburizing steels. Here the nickel is replaced by the copper. The structure would no doubt be better refined by a higher quench. Fig. 14—Heat 202—shows better refinement than Fig. 13, Heat 233, and similar to it, could be still further refined by a higher quench. Fig. 15—Heat 191. The effect of the copper can be seen in the curly structure within the grains. Such a structure is not encountered in straight 1 per cent chromium, 0.20 per cent carbon steel.

Fig. 16—Heat 190—indicates that 1575 degrees Fahr. oil-quench is satisfactory for this composition with its lower critical, and that the 1000-degrees Fahr. temper has brought out a structure which is nicely refined.

Fig. 17—Heat 162—shows refinement of structure somewhat better than Fig. 16, Heat 190, but the ingot structure does not appear completely destroyed, indicating insufficient reduction in forging.

In the tabulation a wide range of carbon content is included so as to give a general idea of the possibilities of the low chromium-copper composition for all purposes including that for cutlery. The rolling, forging, pressing, and stamping qualifications of this material are such as to permit its wide application. Its cost of fabricating will also undoubtedly be less than for similar operations on "stainless" steels. It can also be polished to a high degree. For the corrosion tests, however, the specimens were not polished, but left in the rough to eliminate any resistance to corrosion which would be brought about by the polishing alone.

It is not considered desirable to go into the various applications of this material as from the results of tests and of various heat treatments it can be readily seen that the range of application of the material would be limitless, especially in view of the low cost of production.

SOLUBILITY OF CARBON IN NORMAL AND ABNORMAL STEELS

BY OSCAR E. HARDER AND WILLARD S. JOHNSON

Abstract

The present paper is a continuation of a study on normal and abnormal steels (TRANSACTIONS, A. S. S. T., Vol. 13, 691-1008). In the present investigation a study has been made of the solubility of carbon in typical normal and abnormal steels, making use of longer carburizing times and different carburizing temperatures. The carbon contents of the cases produced have been checked by chemical analyses. The method has been to quench from various temperatures, including the carburizing temperature and lower temperatures, usually by 50 degree Fahr. intervals and note the temperature at which the separation of the carbide first took place.

The results show that for a given carbon content precipitation takes place in the abnormal steel at a higher temperature. It was also found that as the carburizing temperature increases the amount of carbon taken up by the normal and abnormal steels becomes essentially the same. The results seem to be consistent with the previously proposed mechanism of the formation of the characteristic microstructure found in abnormal steels.

INTRODUCTION

THE senior author and associates have published the results of an investigation entitled "Studies on Normal and Abnormal Carburizing Steels."¹ In that paper a diagram was presented to illustrate the probable mechanism of the formation of the microstructure in abnormal carburizing steels. That diagram is reproduced here as Fig. 1 in order to show its relation to this paper. It

¹"Studies on Normal and Abnormal Carburizing Steels," by O. E. Harder, L. J. Weber and T. E. Jerabek, TRANSACTIONS, American Society for Steel Treating. Vol. 13, 1928, pp. 961-1008.

A paper presented before the tenth annual convention of the society held in Philadelphia, October 8 to 12, 1928. Of the authors, who are members of the society, Oscar E. Harder is professor of metallography, school of mines and metallurgy, University of Minnesota and Willard S. Johnson was senior metallurgical engineering student 1927-28 and is now connected with the American Rolling Mill Co., at Middletown, Ohio. Manuscript received July 2, 1928.

was realized at that time that additional experimental work would be required in order to establish the accuracy of the proposed mechanism. The present paper is a continuation of our studies on normal and abnormal steels and has to do particularly with the position of the Acm line or the solubility of carbon in normal and abnormal steels.

MATERIALS USED

Two steels, Nos. 65 and 77, which had been used in the previous investigation were used in this work because they showed characteristic normal and abnormal structures (Figs. 2 and 3) and because they offered some opportunity for correlation between the results obtained in the two investigations. These steels had the following analysis:

Elements	Steel No. 65	Steel No. 77	Steel No. 154*
Carbon	0.012	0.20	0.012
Manganese	0.021	0.43	0.021
Phosphorus	0.005	0.022	0.005
Sulphur	0.038	0.033	0.026
Silicon	Trace		Trace
Copper	0.054		0.052
	0.132		0.116

METHOD OF PROCEDURE

After a considerable amount of preliminary work, a method of procedure was adopted which seemed to give satisfactory results. The size of specimens used was approximately one-half inch in diameter for steel No. 65 and $\frac{5}{8}$ -inch diameter for steel No. 77. The length of the specimens used for carburizing, if they were to be used for microscopic examination, was about $\frac{1}{2}$ inch. The finish on the specimens was obtained by polishing with Nos. 1 and 0 Hubert emery paper. The carburizing containers used were nickel-chromium alloy boxes the inside dimensions of which were 3x4x6 inches. The carburizing compound used was a well-known type marketed by a high grade company. In each test fresh compound was used. The covers of the pots were luted into place with a mixture of fire clay, salt, asbestos fiber, and sufficient water or water glass to make the material plastic.

In carrying out a series of tests, two 6-inch rods of the steels were placed in the bottom of the box, carefully surrounded by car-

*Steel No. 154 was used after the original supply of No. 65 was exhausted.

Table I
Experimental Data on Solubility of Carbon in Normal and Abnormal Steels

Series No.	Steel No.	Carburizing Temperature		Time Hours	Quenching Temperature		Carbon Per Cent	Results
		° C.	° F.		° C.	° F.		
5	77	940	1724	16	940	1724	1.09	Negative
	65						1.06	Positive
	77				912	1675	1.09	Positive
	65						1.06	Positive
6	77	940	1724	16	940	1724	1.13	Slight
	65						1.06	Positive
7	77	1130	2066	16	1130	2066	1.32	Negative
	65						1.35	Negative
	77				1090	1994	1.32	Negative
	65						1.35	Positive
8	77	829	1525	24	1050	1922	1.32	Negative
	77				829	1525	0.72	Negative
	65						0.62	Negative
	77				801	1475	0.72	Negative
	65						0.62	Negative
	77				760	1400	0.72	Negative
9	65	1047	1920	28			0.62	Ferrite
	77				1047	1920	1.37	Negative
	65						1.21	Negative
	77				1022	1875	1.37	Slight
10	65	1055	1931	24			1.21	Positive
	77				1055	1931	1.34	Negative
	65*						1.16	Negative
	77				1025	1880	1.34	Negative
	65						1.16	Negative
11	77	872	1602	24	1000	1832	1.34	Positive
	65						1.16	Positive
	77				872	1602	1.02	Negative
	65						0.96	Positive
12	77	870	1598	30	845	1553	1.02	Positive
	77				870	1598	1.02	Negative
	65						0.96	Positive
13	77	875	1607	24	840	1544	1.02	Positive
	77				875	1607	0.99	Negative
	65						0.81	Positive
	77				850	1562	0.99	Negative
	65						0.81	Positive
	77				830	1526	0.99	Positive

*New supply of No. 65.

burizing material; above these the desired number of couplets of the two steels were placed for microscopic examination. The carburizing boxes were then sealed, heated in an electric furnace to the desired temperature, held at that temperature for the desired length of time shown in Table I, and one couplet quenched in water from the carburizing temperature. The temperature then was lowered, usually 50 degrees Fahr., held at that temperature one hour, and a second couplet quenched, and the temperature again lowered, and so on until the desired number of specimens had been quenched.

The bars for chemical analysis were left in the pot to cool down to room temperature, after which turnings were removed from the hypereutectoid zone and the carbon content carefully

determined making use of the Flemming direct combustion method. Great care was taken in the case of all the specimens to remove surface scale, grease, etc. The results of these tests are shown in Table I.

DISCUSSION OF RESULTS

The data contained in Table I have been used to construct Fig. 4. Neither Table I nor Fig. 4 contain all the points which were determined in connection with this diagram. For example,

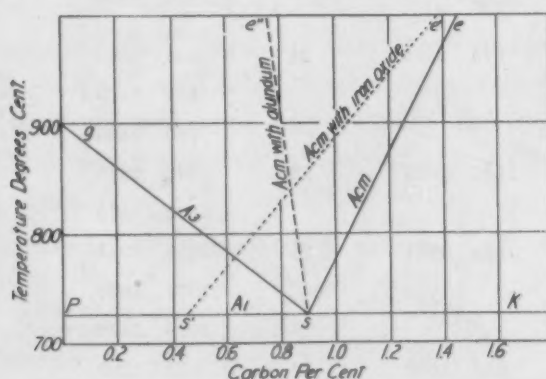


Fig. 1—Diagram to Illustrate the Probable Mechanism of the Formation of the Microstructure in Abnormal Carburizing Steels.

if on quenching a specimen was shown to contain carbide, then those which were quenched from lower temperatures even though they were examined were not reported in the table or in the diagram.

The points used in Fig. 4 are not as consistent as might be desired, but they do seem to show a definite, positive difference in the temperatures at which the carbide separates out in the two different types of steel.

In the case of the Ac1 line of steel No. 65, a certain amount of irregularity is noted in the carbon content of 0.96 to 1.06 per cent. These steels showed excess of carbide when quenched directly from the carburizing temperature. The line has, therefore, been drawn in somewhat more on the evidence obtained by tests on the steels which were carburized at higher temperatures and which did not show excess carbide when quenched from the carburizing temperature.

In the case of the normal steel, two points are somewhat out of line. One is the steel carburized at 1725 degrees Fahr., (940

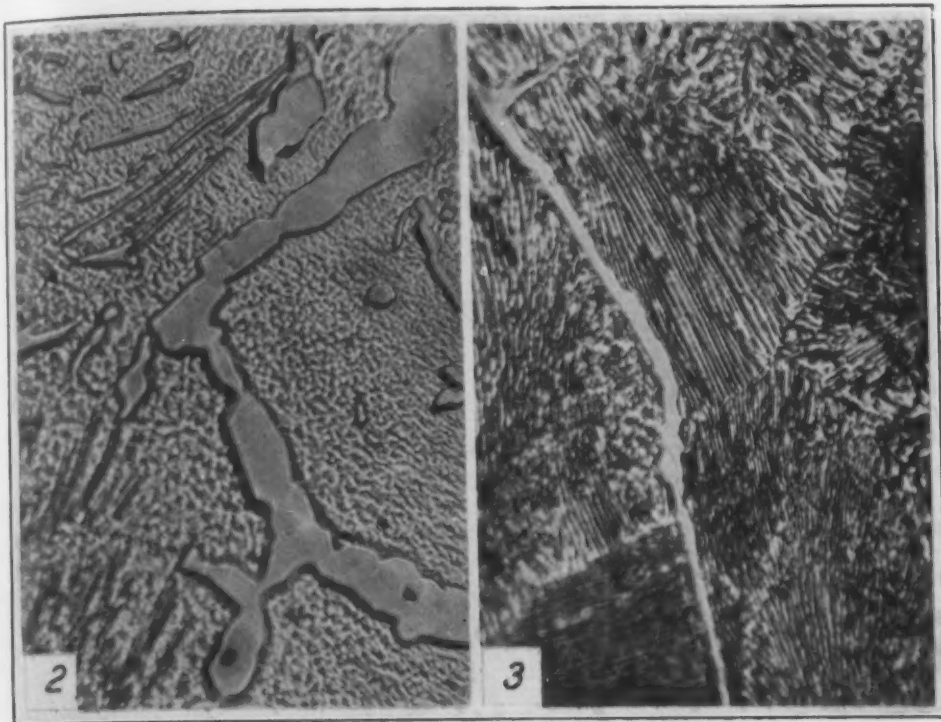


Fig. 2—Photomicrograph of Steel No. 65. Carburized at 1725 Degrees Fahr. (940 Degrees Cent.), and Cooled in Pot. $\times 1000$. Fig. 3—Photomicrograph of Steel No. 77. Carburized at 1725 Degrees Fahr. (940 Degrees Cent.) and Cooled in the Pot. $\times 1000$.

degrees Cent.); the other is a specimen of series 6 carburized at 1725 degrees Fahr. (940 degrees Cent.) and quenched from that temperature, which showed 1.13 per cent carbon and a slight amount of cementite present.

MICROSCOPIC EXAMINATION

Only certain of the more significant microstructures are being submitted with this paper. Figs. 5 and 6 from series 5 show the microstructures obtained with steels No. 65 and 77 respectively, after carburizing 16 hours at 1725 degrees Fahr. (940 degrees Cent.) and quenching from the carburizing temperature. It will be observed that excess carbide is shown in the abnormal steel while it is not present in the normal steel. Figs. 7 and 8 from this same series show the increasing amount of cementite in the abnormal steels and the appearance of cementite in the normal steels when they were quenched from 1675 degrees Fahr. (912 degrees Cent.) after having been carburized at 1725 degrees Fahr. (940 degrees Cent.).

Fig. 9 shows the beginning of the formation of cementite in steel No. 65 which had been carburized at 2065 degrees Fahr. (1130 degrees Cent.) and quenched from 1675 degrees Fahr. (912 degrees Cent.). Carbide was absent in this series when the steel was quenched from the carburizing temperature. In steel No. 77, also carburized at 2065 degrees Fahr. (1130 degrees Cent.) the carbide was absent in all of the specimens tested. Unfortunately

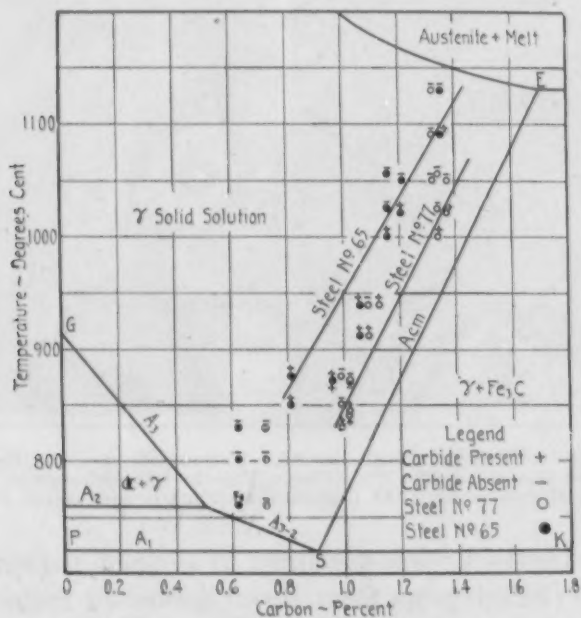


Fig. 4—Diagram Showing the Solubility of Carbon in Normal and Abnormal Steel.

the lowest temperature at which a specimen was quenched was 1920 degrees Fahr. (1050 degrees Cent.), the microstructure of which is shown in Fig. 10 and the absence of cementite is evident.

Of the specimens in series 9 carburized at 1915 degrees Fahr. (1047 degrees Cent.), Figs. 11 and 12 show the more significant microstructures obtained. Fig. 11 is for steel No. 65 carburized at 1915 degrees Fahr. (1047 degrees Cent.) and then quenched from 2050 degrees Fahr. (1022 degrees Cent.). It shows the formation of massive cementite and in addition to that troostitic areas. This seems to be a very important microstructure and probably indicates the mechanism of the formation of the typical structure found in abnormal steels. Even at this rapid rate of cooling it appears that the cementite is taken away from the austenite to such an extent that certain areas form troostite on quenching rather

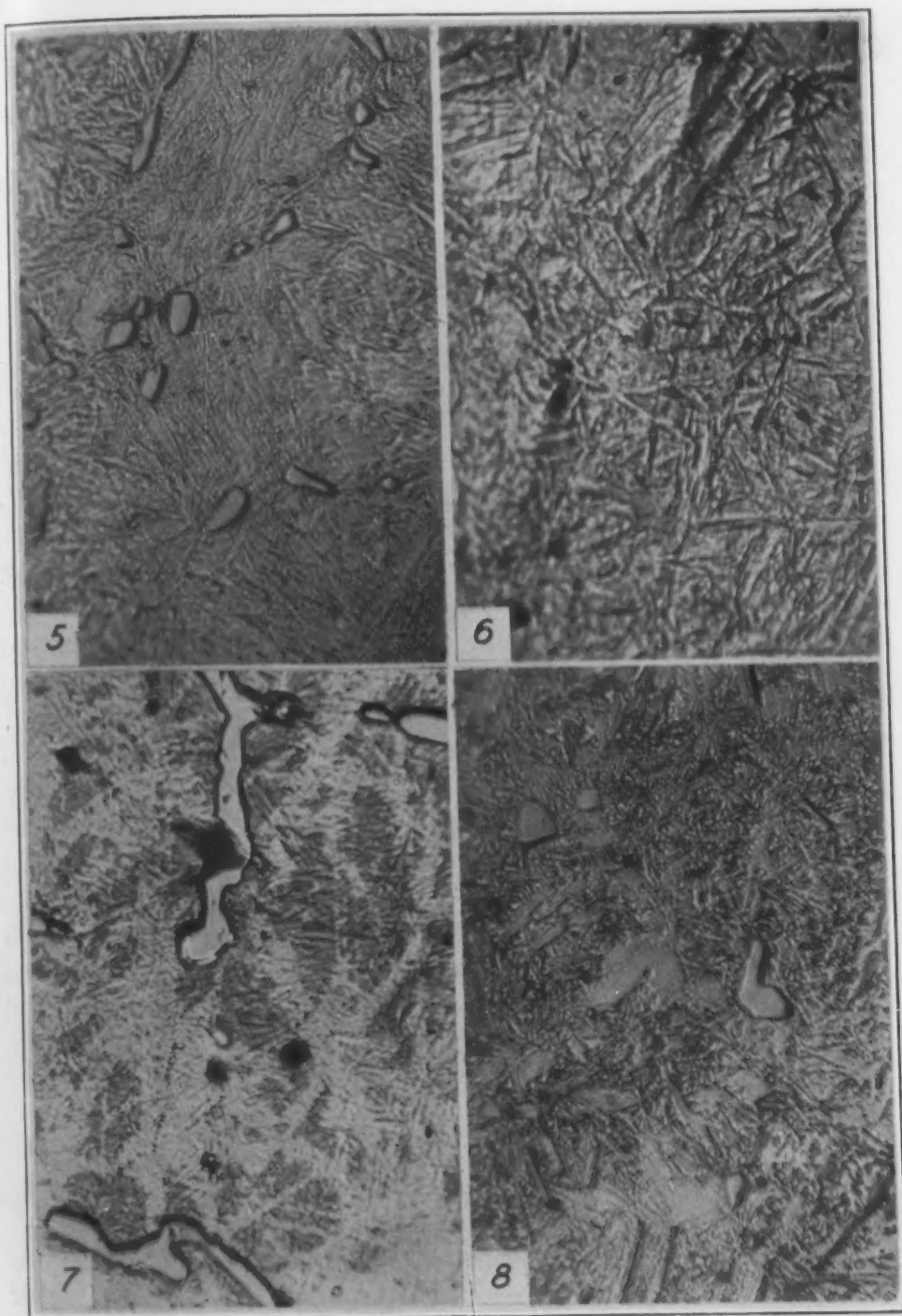


Fig. 5—Photomicrograph of Series 5, Steel No. 65. Carburized 16 Hours at 1725 Degrees Fahr. (940 Degrees Cent.). Quenched from Carburizing Temperature. $\times 1000$. Fig. 6—Photomicrograph of Series 5, Steel No. 77. Carburized 16 Hours at 1725 Degrees Fahr. (940 Degrees Cent.). Quenched from Carburizing Temperature. $\times 1000$. Fig. 7—Photomicrograph of Series 5, Steel No. 65. Carburized 16 Hours at 1725 Degrees Fahr. (940 Degrees Cent.). Quenched from 1675 Degrees Fahr. (912 Degrees Cent.). $\times 1000$. Fig. 8—Photomicrograph of Series 5, Steel No. 77. Carburized 16 Hours at 1725 Degrees Fahr. (940 Degrees Cent.). Quenched from 1675 Degrees Fahr. (912 Degrees Cent.). $\times 1000$.

than martensite. Fig. 12 shows a small amount of cementite forming adjacent to the grain boundaries.

A new supply of steel No. 65 was used in series 10-13 inclusive but it was of the same type and the McQuaid-Ehn test showed that the new supply had the same degree of abnormality as nearly as could be judged. It was, therefore, considered that the new stock could be used with reliable results.

Figs. 13 and 14 show the beginning of the formation of cementite in steels No. 65 and 77 respectively, carburized at 1930 degrees Fahr. (1055 degrees Cent.) and quenched from 1825 degrees Fahr. (998 degrees Cent.). The difference in carbon content causes these steels to show cementite formation at this same temperature. It will be observed that there is some difference in the way in which the formation of carbide begins in the two different kinds of steel.

Figs. 15 and 16 show the results obtained in series 11. In Fig. 15 we have the presence of cementite shown when quenched from the carburizing temperature. The normal steel when quenched from this temperature showed no cementite, but when quenched from a lower temperature, 1550 degrees Fahr. (845 degrees Cent.) showed the beginning of the formation of cementite seen in Fig. 16.

The significant microstructures found in series 12 are shown in Figs. 17 and 18. It will be noted that the carburizing temperature was low, 1600 degrees Fahr. (870 degrees Cent.), and in the microstructure it will be observed that the structure is somewhat different from that found in the other photomicrographs. It appears that a very small amount of cementite in spheroidized form is separating out from the ground mass of martensite in both cases. In that connection it should be pointed out that the normal steel was quenched from 30 degrees lower temperature than the abnormal.

Fig. 19 shows the beginning of the formation of cementite in the abnormal steel from series 13. The steel was carburized at 1607 degrees Fahr. (875 degrees Cent.) and quenched from 1560 degrees Fahr. (850 degrees Cent.). The amount of cementite present would indicate that its precipitation began at a somewhat higher temperature. Fig. 20 shows the beginning of the formation of cementite in the normal steel when quenched from 1525 degrees Fahr. (830 degrees Cent.). A small amount of cementite found

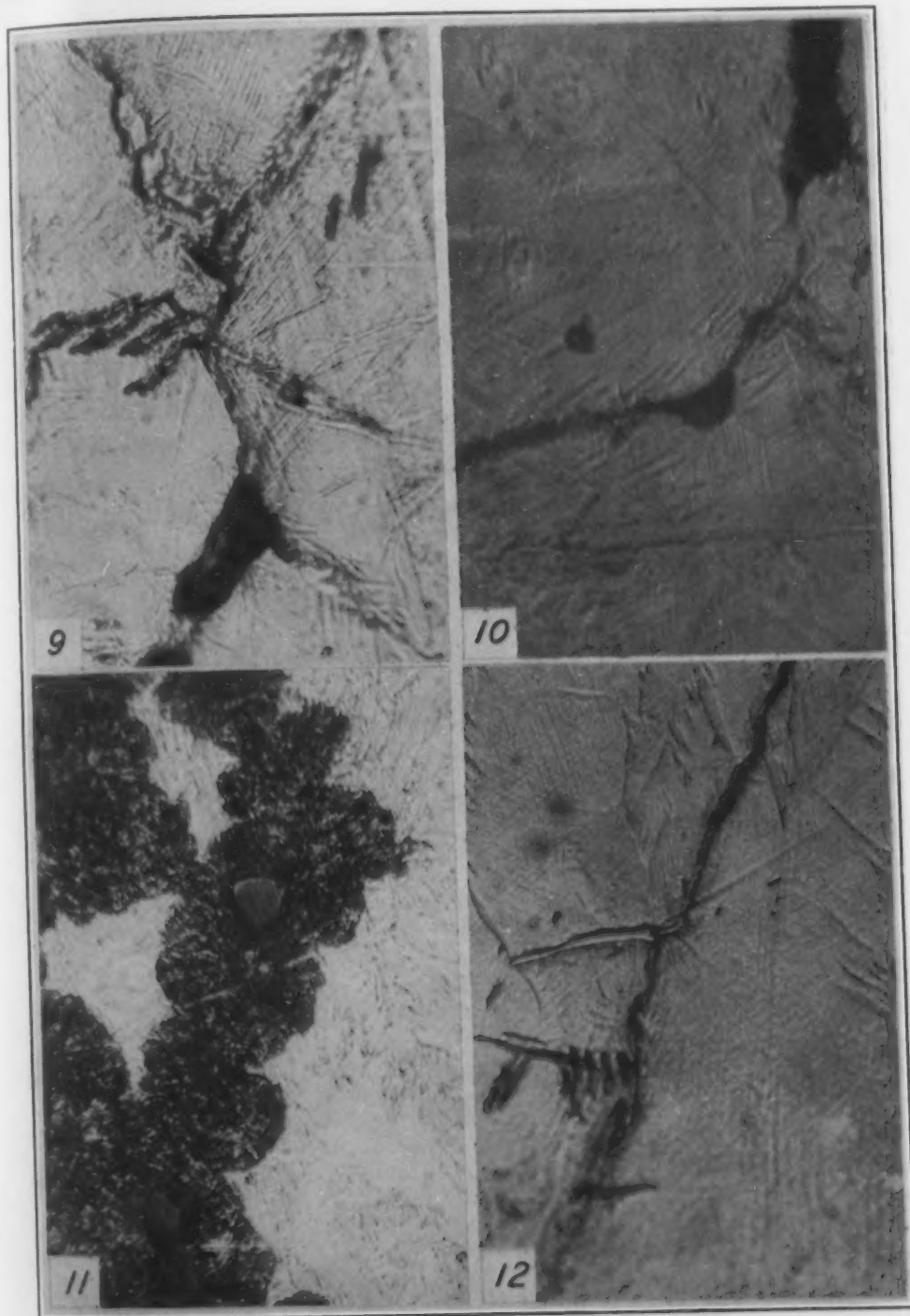


Fig. 9—Photomicrograph of Series 7, Steel No. 65, Carburized at 2065 Degrees Fahr. (1130 Degrees Cent.) and Quenched from 1995 Degrees Fahr. (1090 Degrees Cent.). $\times 1000$.
 Fig. 10—Photomicrograph of Series 7, Steel No. 77, Carburized at 2065 Degrees Fahr. (1130 Degrees Cent.) and Quenched from 1920 Degrees Fahr. (1050 Degrees Cent.). $\times 1000$.
 Fig. 11—Photomicrograph of Series 9, Steel No. 65, Carburized at 1920 Degrees Fahr. (1045 Degrees Cent.) and Quenched from 1870 Degrees Fahr. (1020 Degrees Cent.). $\times 1000$.
 Fig. 12—Photomicrograph of Series 9, Steel No. 77, Carburized at 1917 Degrees Fahr. (1045 Degrees Cent.) and Quenched from 1870 Degrees Fahr. (1022 Degrees Cent.). $\times 1000$.

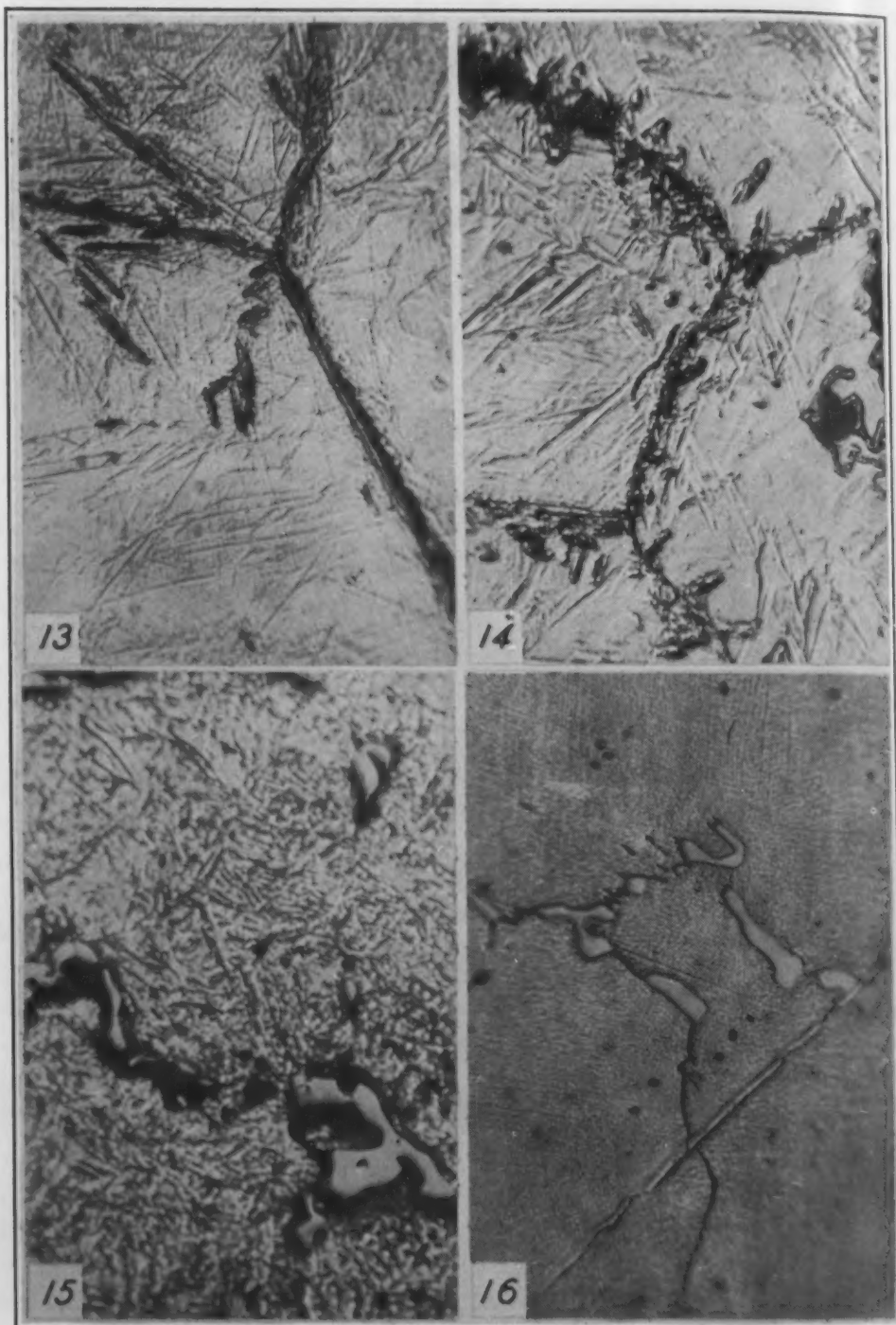


Fig. 13—Photomicrograph of Series 10, Steel No. 65, Carburized at 1930 Degrees Fahr. (1055 Degrees Cent.) and Quenched from 1825 Degrees Fahr. (998 Degrees Cent.). $\times 1000$.
 Fig. 14—Photomicrograph of Series 10, Steel No. 77, Carburized at 1930 Degrees Fahr. (1055 Degrees Cent.) and Quenched from 1825 Degrees Fahr. (998 Degrees Cent.). $\times 1000$.
 Fig. 15—Photomicrograph of Series 11, Steel No. 65, Carburized at 1600 Degrees Fahr. (870 Degrees Cent.) and Quenched from the Same Temperature. $\times 1000$.
 Fig. 16—Photomicrograph of Series 11, Steel No. 77, Carburized at 1600 Degrees Fahr. (870 Degrees Cent.) and Quenched from 1555 Degrees Fahr. (845 Degrees Cent.). $\times 1000$.

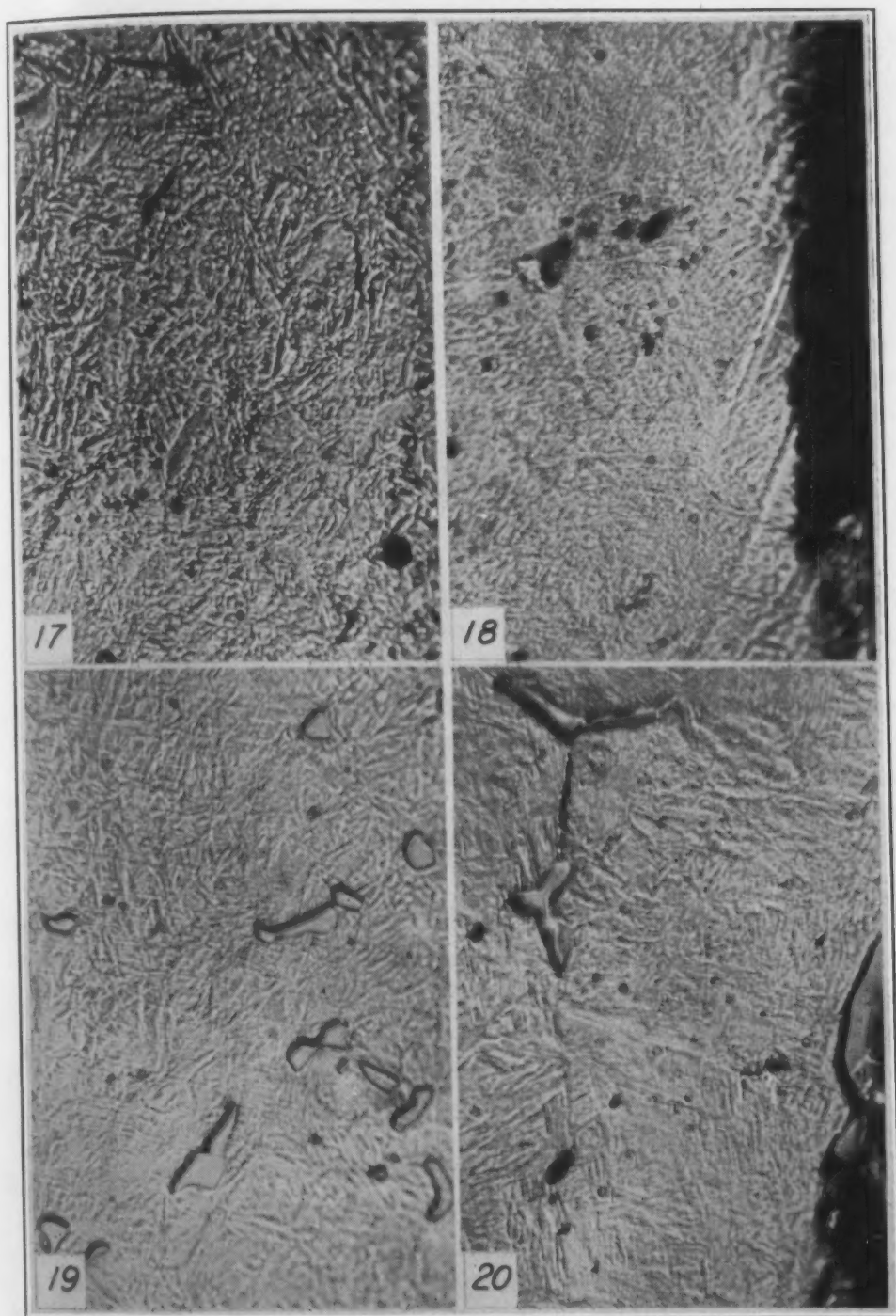


Fig. 17—Photomicrograph of Series 12, Steel No. 65, Carburized at 1600 Degrees Fahr. (870 Degrees Cent.) and Quenched from 1600 Degrees Fahr. (870 Degrees Cent.). $\times 1000$.
Fig. 18—Photomicrograph of Series 12, Steel No. 77, Carburized at 1600 Degrees Fahr. (870 Degrees Cent.) and Quenched from 1545 Degrees Fahr. (840 Degrees Cent.). $\times 1000$.
Fig. 19—Photomicrograph of Series 13, Steel No. 65, Carburized at 1605 Degrees Fahr. (875 Degrees Cent.) and Quenched from 1560 Degrees Fahr. (850 Degrees Cent.). $\times 1000$.
Fig. 20—Photomicrograph of Series 13, Steel No. 77, Carburized at 1605 Degrees Fahr. (875 Degrees Cent.) and Quenched from 1525 Degrees Fahr. (830 Degrees Cent.). $\times 1000$.

would indicate that its formation was started only slightly above this temperature.

ACCURACY OF RESULTS

The quenching tests included in this paper are limited to those on cooling from a higher temperature. In some of the early series not reported here, attempts were made to carburize specimens, cool them slowly, reheat to different temperatures and quench. The results were erratic and that line of study was discontinued. It appeared that the reheating of the specimens caused some diffusion of the carbon and possibly changed the carbon content of the case.

Great care was taken in the selection of the material for the carbon determinations, but there is a possibility of slight errors in selection of material. It was customary to determine the depth of the hypereutectoid case and then to machine off a smaller amount of metal than that which was known to have hypereutectoid structure.

No attempt was made to quench the specimens at smaller intervals than 50 degrees Fahr. and the results cannot be considered reliable to a greater degree of accuracy than that value.

Some work has been done on the thermal analysis, but that method introduced such serious experimental difficulties that it was discontinued and not reported here. Thermal analysis involves the obtaining of a uniform hypereutectoid structure throughout the specimen to be tested, and the retaining of that structure throughout the thermal analysis. It may be possible to develop an experimental technique which will make it possible to re-study the position of the Acm lines in these steels by means of thermal analysis, but that has not been done to date.

SUMMARY OF RESULTS AND CONCLUSIONS

The results which have been obtained seem to the authors to warrant the following conclusions.

1. An experimental method for the study for the location of the Acm line in normal and abnormal steel has been developed.
2. This experimental method has been applied to a typical normal steel and to a typical abnormal steel at several different temperatures over the range of 1525 to 2068 degrees Fahr. (829 to 1130 degrees Cent.).

3. As the temperature increased, the Acm lines of these steels converged.

4. The Acm line observed for the normal steel was found to lie parallel to the line published in the literature; but is shifted to the left so that the eutectoid point would come at about 0.75 per cent carbon instead of 0.9 per cent carbon.

5. The Acm line for the abnormal steel is shifted still further to the left and if extended would cut the A_1 line at a carbon content of about 0.55 per cent.

6. At the lowest temperature studied the carbon content of the case of the abnormal steel is much less than that of the normal steel and as the carburizing temperature increases, the carbon content of the abnormal steel approaches that of the normal steel. At temperatures of 2018 degrees Fahr. (1130 degrees Cent.) the carbon content of the abnormal steel is even greater than that of the normal steel.

7. The results at low carburizing temperatures are somewhat less satisfactory because of the apparent conditions of these steels, particularly the abnormal steel which shows a piling up of the cementite at the edges of the specimens.

8. These results seem to be in general agreement with what would be expected from the theoretical considerations proposed by Harder, Weber and Jerabek and show a decided shifting of the Acm line in the abnormal steel.

9. The low carbon content of the abnormal steel at low temperatures seems to offer a reasonable explanation for the unsatisfactory results obtained in commercial carburizing of such steels particularly when low temperatures are used.

10. These results also seem to indicate that satisfactory commercial carburizing of these abnormal steels may be carried out providing high temperature is employed.

11. The observations of Sefing² with respect to changing abnormal steel to normal steel by heating at elevated temperatures may find at least a partial explanation in the work which shows that at high temperature the carbon solubilities in normal and abnormal steels are essentially the same.

12. Warpage noted by Hildorf³ in abnormal steels has been

²Bulletins Nos. 5 and 18, Michigan Engineering Experiment Station.

³*Iron Age*, Vol. 109, 1922, p. 1807.

found to be prevalent in the abnormal steels used in this investigation.

DISCUSSION

Written Discussion: By Frederick G. Seifing, metallurgist, Michigan State College, East Lansing, Mich.

Tammann's "Text Book of Metallography"¹ shows in Figs. 147, 148 and 149 a position of the A_{cm} line similar to the ones presented by the authors except, however, that the iron-carbon mixtures referred to by Tammann are of white cast irons.

On page 248 Tammann says: "By quenching a steel of 0.9 to 2.0 per cent carbon, martensite is formed from the cementite needles, while the ground mass consists of the gamma solid solution (austenite). At the boundary between the austenite and cementite needles the ability of spontaneous formation of the martensite is considerably greater than in the austenite itself. This phenomenon is quite general. At the boundary of a crystal and its undercooled melt metastable forms frequently appear."

From the above it appears that the excess cementite and the austenite form the first martensite and that the last martensite is formed by the remaining austenite. The authors have shown however that this is not always true since several photomicrographs have been presented which indicate that the cementite is the last to form martensite.

It is of more than passing significance to know how far from the recognized A_{cm} line some steels precipitate cementite. This knowledge will probably help us to understand why some steels can have their cementite distributed uniformly only with difficulty. Very probably all commercial steels deviate somewhat to the right or left from the familiar A_{cm} line particularly when this curve is determined by the method presented by the authors. It would be very interesting to know how closely the thermal analyses of the steels presented in this paper would place the A_{cm} lines to those given in Fig. 4 of the paper.

Steel No. 77 has twice the sulphur, four times the phosphorus, and six times the manganese as No. 65. Therefore, the fact that steel No. 65 shows a higher precipitation temperature for cementite than No. 77 cannot be attributed to only the difference in normality between these two steels. In order to arrive at definite conclusions it is obvious that very similar steels must be used for investigation, excepting, of course, differences in the normality.

Only qualitative data on the relative carbon content of normal and abnormal steels have been available before the presentation of this paper. The authors have contributed valuable information in presenting quantitative data on the carbon content of normal and abnormal steels.

The high temperature heat treatment to render abnormal steels normal as presented in the Michigan Engineering Experiment Station Bulletin No.

¹A Text Book of Metallography by G. Tammann, translated by R. S. Scott and L. G. Swenson.

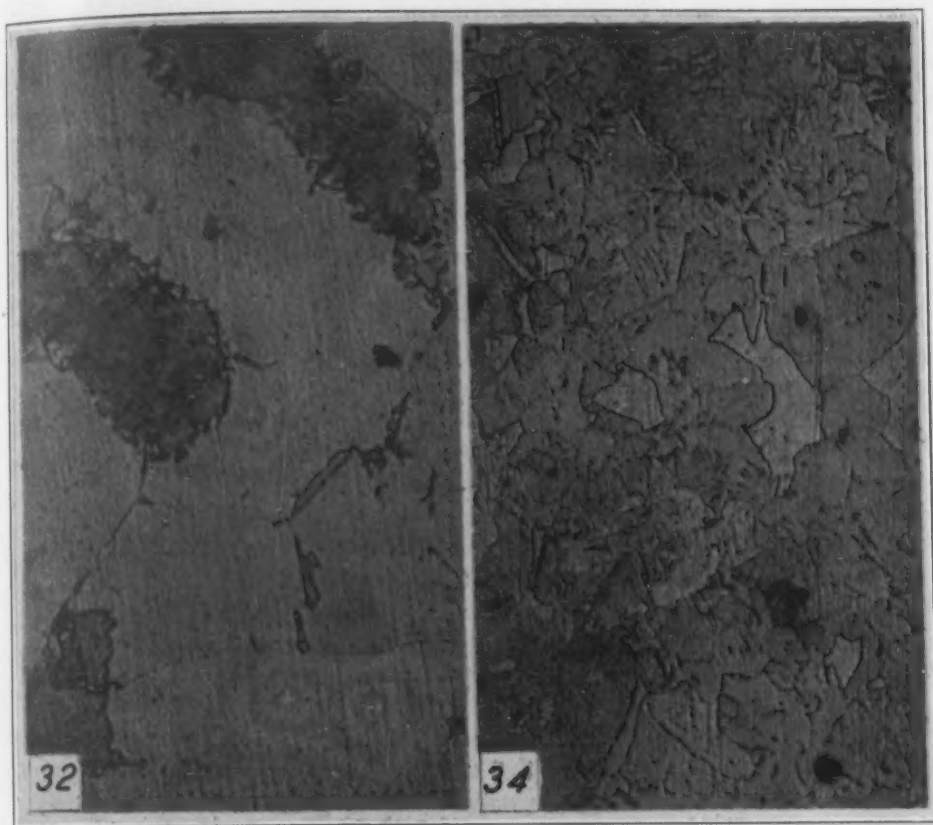


Fig. 32—Photomicrograph of S.A.E. 1020 Steel, Cooled in Lime from 2000 Degrees Fahr. (1094 Degrees Cent.). Fig. 34—Photomicrograph of S.A.E. 1020 Steel, Cooled in Lime from 2025 Degrees Fahr. (1107 Degrees Cent.).

13 and exceptions to that heat treatment² may probably be explained by the different positions that the A_{cm} line takes in various carburizing steels. Thus the higher the A_{cm} line of any steel the more difficult it is to obtain the normal structure.

I believe there is something unusual in the significance of Fig. 11 in the author's paper, which figure reminded me of rather striking photomicrographs in bulletin No. 13 of the Michigan Engineering Experiment Station. These two photomicrographs were obtained from a sample of very abnormal SAE 1020 steel which had been finally heated in a sealed tube containing a little carbon to 2000 degrees Fahr. (1092 degrees Cent.) Fig. 32 and 2025 degrees Fahr. (1107 degrees Cent.) Fig. 34 and cooled in lime. Both the specimens of Figs. 32 and 34 had been changed to normal steel by their respective heat treatments. The entire case of the specimen heated to 2025 degrees Fahr. (1107 degrees Cent.) was unusually uniform and ideally normal.

The specimen of Fig. 32 showed no pearlite and the ferrite grains were clearly distinguishable. The dark areas appear to be troostitic at high

²TRANSACTIONS, American Society for Steel Treating, Vol. XIV, page 355.

magnification (1500), but this constituent is difficult to understand in view of the heat treatment given the specimen. Fig. 32 shows the structure of the core with slightly shaded areas indicating that the pearlite is almost completely diffused into the ferrite. It may be added that specimens cooled in lime from 1985 degrees Fahr. (1085 degrees Cent.) and 2085 degrees Fahr. (1141 degrees Cent.) gave the familiar pearlitic-ferritic microstructure.

The above described phenomenon of troostite and martensite in slowly cooled steels was obtained with one other sample of SAE 1020 steel and with Armeo ingot iron by treating the ingot iron as follows: carburize 1700 degrees Fahr. (928 degrees Cent.) 8 hours, 2025 degrees Fahr. (1107 degrees Cent.) 1 hour, cool in lime. This peculiar structure was retained in several samples of both ingot iron and SAE 1020 steel even after a carburizing treatment at 1700 degrees Fahr. (928 degrees Cent.) for 8 hours.

Several of these unusual specimens were submitted to various metallurgists who suggested that the structure seemed to be troostite and martensite but no one has offered any explanation except that the steel must have been rapidly cooled which, however, was not the case.

The authors are to be commended upon showing us another variation in an already complex situation which may, however, be understood more clearly after we have learned to apply the authors' information accurately.

Written Discussion: By H. A. Schwartz, National Malleable and Steel Castings Co., Cleveland, O.

The writer welcomes with the greatest interest the information of Harder and Johnson that in the abnormal steels the A_{cm} line is apparently shifted to the left. Even though the authors themselves are able to point to certain discrepancies and minor contradictions in their own work, their observations seem to furnish ample basis for their conclusion that at least in a qualitative sense, the relation of the A_{cm} lines is as they consider it to be.

Although we have not yet sufficient ground for positive assertion, the writer would like to point to an application of the present author's conclusions which seems to him entirely probable and which is certainly interesting.

It is well known that in the absence of proper precautions malleable iron is sometimes produced having a "picture frame rim," i.e. an edge of pearlite surrounding an otherwise normal structure. The available information as to the circumstances under which this phenomenon can occur points to the generalization that when decarburization precedes graphitization the rim is observed to occur.

Now we may explain this phenomenon very plausibly on the assumption that considerable decarburization is accompanied by some surface oxidation and the fact that Schenck, Matsubara and perhaps others have recorded gas equilibria which prove that in the presence of oxygen in the solid phase cementite may be stable toward graphite although in pure iron carbon systems the reverse is true.

Dr. Harder's work now confirms this speculation further for the displacement of the A_{cm} line to the left (by oxygen) in abnormal steels may bring it to the left of the A_{gr} line thus presenting further evidence that in the presence of oxygen Fe-Fe₃C may be the stable system instead of the Fe-C system as is more usual. This, of course, postulates that oxygen does not have any great effect on the locus of A_{gr} , a matter upon which the writer has no information.

If the Schenck and Matsubara data apply to systems in which oxygen is a component of the solid phase, then we may certainly interpret them as proof of the stability of the system Fe₃C-Fe when contaminated by oxygen and if Fe₃C is stable toward carbon in such systems, carbon as cementite (or should we say oxocementite, though Schenck does not seem to have found evidences of oxygen in that phase?) must be less soluble in gamma iron containing oxygen (Schenck's oxo-austenite) that is carbon as the element. But in pure iron carbon alloys, Fe₃C being metastable, carbon is more soluble than as the element. Therefore oxygen in the solvent phase, ferrite, shifts the relative positions of the A_{gr} and A_{cm} lines.

Dr. Harder now teaches us that this shift is at least in part though possibly wholly due to a displacement of the A_{cm} line. The conclusion is entirely in accord with the gas equilibria for the system Fe-Fe₃C with and without contamination by oxygen and thus forms a significant addition to our knowledge of equilibria in the system Fe-C-O.

The writer would point to another interesting fact shown by Harder and Johnson which they themselves have passed over without comment. The data of Table I show that, with one exception, (carburization at 1130 degrees Cent.) the carbon content of the hypereutectoid zone of the normal steel is always higher than that of the abnormal. We have no data from the authors' paper as to the magnitude of any carbon gradient in this zone they having, by inference at least, considered the carbon content as uniform in this region.

If we assume that the carbon content of the surface increases until the gamma iron is saturated and that no further increase of carbon concentration which would involve the formation of cementite, can occur, then this confirms the lesser solubility of carbon in the abnormal steel.

Presumably the carbon concentration in the outer layers of the steel is an expression of the carbon content of austenite which is in equilibrium with the case hardening mixture through the intervention of the corresponding gas phase. Taking advantage of the fact that the law of conservation of energy requires that things in equilibrium with the same thing are in equilibrium with each other, we may then say that the vapor pressure of carbon from each of the two austenites, from abnormal and normal steel respectively, is the same, hence that for equal concentrations of carbon the vapor pressure of carbon from abnormal austenite is the higher and hence further that abnormal austenite in equilibrium with cementite will be of lower carbon concentration than normal austenite, thus again confirming the conclusion of the authors by chemical instead of metallographic reasoning.

It will be further noted in Table I that no instances are shown in which the normal steel quenched from carburizing temperatures contains free carbide but five cases are listed where this is true of abnormal steel.

It thus appears that in abnormal steels the vapor pressure of carbon from carbide must be lower than that from the carburizing mixture, which is probably similar to that of carbon, while in normal steels the vapor pressure of carbon from the carbide is in excess of that from the carburizing mixture, hence the carbon vapor pressure of the carbide of abnormal steels is lower than in the case of normal steel. These pressures are entirely independent of the solvent phase and would exist unchanged in the absence of any solvent.

It seems to follow therefore that the two carbides can not be identical and a plausible assumption is that the carbide of abnormal steel is contaminated with oxygen.

The observed formation of free cementite at carburizing temperatures lends weight to the writers' assumption that in oxygen bearing metal the system $\text{Fe-Fe}_3\text{C}$ may be stable.

The writer is grateful to the authors for developing data bearing upon this point.

Written Discussion: By B. M. Larsen, U. S. Bureau of Mines, Pittsburgh, Pa.

The authors give some interesting data relating to the fundamental causes of abnormal structures in carburized steels. Their work would be much more convincing if it had included some thermal analyses to determine the position of the A_{cm} points under conditions insuring a closer approach to equilibrium. It is certainly surprising to find so much variation between the positions of the A_{cm} line as ordinarily accepted and those determined by the authors. This is especially true of the low values for the eutectoid point (0.75 and 0.55 per cent) indicated by these curves.

Carbon gradient curves on carburized cylinders of steels with structures varying from very normal to extremely abnormal have been determined at the Bureau of Mines laboratory. Comparison of these curves with microstructures through the case at the same scale showed that in no case was there any precipitation of hypereutectoid cementite in zones containing less than 0.90 per cent carbon. It would be interesting to obtain from the authors the details of procedure used in quenching the samples. It is possible that the removal of pairs of samples from the carburizing box in the furnace and immersion in the quenching medium may not have been quite rapid enough to freeze the equilibrium existing in the box, especially since the precipitation of cementite occurs near the surface of the specimens, which would be the portions cooling first during the transfer. Also, the carbon analyses as given are apparently the average contents of the outer zone of the case. The actual carbon content decreases continuously from point to point, progressing inward from the surface, and the points at which the precipitation of cementite was observed under the microscope may have been higher in carbon than the average value reported. Both

of these errors, if present, would tend to shift the lines upward and to the left of the A_{cm} line usually accepted for the iron-carbon diagram.

As to the apparent difference in ease of cementite precipitation in the two steels, this might be due to the rather large difference in manganese contents. A commercial steel of the type indicated by the analysis for No. 65 would be likely to contain a number of small inclusions, and it is just possible that these may have acted as nuclei to facilitate the quicker separation of small cementite aggregates. This steel may also contain a certain amount of dissolved oxygen and this, combined with the low manganese content and the possible presence of small inclusions, would account for its extremely abnormal structure. Steels of the analysis of No. 77, with 0.43 per cent manganese, are usually normal if they have been properly deoxidized and cleansed during manufacture.

The early separation of hypereutectoid cementite nuclei should favor the growth of larger and more irregularly scattered aggregates of this phase. However, the changes resulting in highly divorced cementite are chiefly dependent upon the conditions favoring diffusion of carbon in the pearlite grains as they form at the A_r point. Whatever the true equilibrium position of the A_{cm} line may be, with ordinary cooling rates, one should expect a certain amount of undercooling below this line in all samples. Clean, uniform and stable crystalline structures and the presence of manganese, chromium, etc. in solution probably favor such under cooling and tend to cause the cementite to be distributed evenly at grain boundaries and along cleavage planes of the gamma iron grains.

Authors' Reply to Discussion

O. E. Harder: I have answered most of the questions contained in the paper by Mr. Sefing in my previous remarks in which I discussed the attempt which we made to determine the A_{cm} line by thermal analysis. That is an exceedingly difficult determination to make, in addition to the possibility of carbon migration, which I mentioned before.

I think I have nothing to say about Mr. Schwartz' paper except that I appreciate very much his remarks.

In regard to the remarks by the last discussor, the time consumed in quenching the specimens was very small. The specimens were kept in the carburizing boxes and they were arranged with loops of wire so that from the time they were taken out of the carburizing material until they were in the quenching medium was a matter of two or three seconds. At any rate, the results are strictly comparable in these two steels.

As regards the chemical analysis, I must say that the carburizing was carried out over a long period of time in order to get a sufficient depth of case of fairly uniform structure so we could machine off a sufficient amount for chemical analysis. I daresay that there may be some gradient of carbon from the outside inward. We were careful, however, to limit the amount of material taken for chemical analysis to that depth of the case which would be characterized as a hypereutectoid zone.

With regard to the position of the eutectoid point, I am of the opinion that our results indicate that the eutectoid point in these steels was shifted

to the left, and I wish to refer to Fig. 4, for a little more discussion. You will note that in the case of one of the abnormal steels, we found ferrite present in the material as quenched from the carburizing box. I am of the opinion that this A_{cm} line of the abnormal steel is shifted to the left and that that line probably intersects with the A_s line, causing a system which is supersaturated at that temperature with reference to ferrite, and that that is the mechanism whereby excess ferrite separates out adjacent to cementite grains. Because of the presence of cementite, a seeding effect which is well known, the austenite adjacent to that cementite was reduced to a low carbon content and intersects the A_s line. We then have a reaction, during which you have the precipitation of ferrite, and that is the ferrite which is found adjacent to the cementite, and during this reaction we have a shifting back to the eutectoid point, at which temperature we get the formation of some rather normal pearlite in some of our abnormal steels. I hope that we may be able during the coming year to do some more work on these hypoeutectoid zones, because we have worked only in the hypereutectoid so far.

I agree with Mr. Larsen in that thermal analysis of these steels would be quite convincing, but I think Mr. Larsen will agree with me that the location of the A_{cm} line by means of thermal analysis is rather difficult. I consider also that as far as commercial importance is concerned we are more interested in the reactions taking place more nearly under the conditions of plant practice, which of course are not equilibrium conditions. As previously mentioned in my discussion, we did a little work on thermal analysis and found so much difficulty that the work was not continued. It would be interesting if Mr. Larsen finds it possible to check up that phase of the investigation. I might point out to Mr. Larsen that the value 0.90 for the eutectoid point is not a well established value. It is well known that many steels which are not usually considered alloy steels will show essentially a pearlitic structure with only 0.80 carbon and in some cases with much lower carbon contents.

I have already discussed the time involved in transferring the specimen from the carburizing box to the quenching bath.

There is, to be sure, a marked difference in the manganese content of the two steels, and I am inclined to believe as Mr. Larsen points out that the manganese content of a steel may be somewhat indicative of the normality of the steel, although I do not believe that this point has been thoroughly established. Small inclusions do appear, at least in certain cases, to have an influence on the cementite precipitation. Whether these small inclusions function as nuclei or have a precipitating effect on cementite, or whether they simply indicate a region which may have a high oxygen content, I am not at the present time prepared to say. Perhaps either condition would be favorable to early precipitation of the cementite.

My discussion in reply to others has given my conception of the mechanism of the formation of abnormal structure found in these steels, and that mechanism seems to be more in harmony with our experimental results than the point suggested by Mr. Larsen.

AUSTENITE DECOMPOSITION AND LENGTH CHANGES IN STEEL

BY EDGAR C. BAIN AND WILLIS S. N. WARING

Abstract

This paper discusses the continuous change in axial length of a number of steel cylinders occurring during quenching at various rates. The equipment for recording these length changes is described with suggestions for its improvement. The changes in length of steel rods accompanying tempering and liquid air refrigeration are also presented.

All of these data, together with some magnetic measurements on the same steels made at the Research Laboratories of the General Electric Co., are considered from the viewpoint of their evidence regarding austenite behavior during decomposition. Particularly are the possibilities of the influence of quenching stresses on the proportion of martensite and austenite discussed.

It is suggested in the paper that the method employed in measuring length changes during quench may be used in a practical way to evaluate the quenching efficiency of various quenching mediums. The curve of length-change plotted against time during quench in a known medium gives some fundamental notion of the nature of the steel.

The paper is entirely preliminary in character; the methods themselves are stressed, with only comparatively few of the many possible investigations carried out to exemplify the significance of the study.

The two steels studied are an oil-hardening die steel and a stainless steel.

INTRODUCTION

LENGTH-CHANGE accompanying tempering in quenched steels has often been measured and has provided much information concerning the extent of the preserved austenite and the na-

A paper presented before the tenth annual convention of the society held in Philadelphia, October 8 to 12, 1928. Of the authors, E. C. Bain, a member of the society, and formerly associated with the Union Carbide and Carbon Research Laboratories, is now connected with the Research Bureau of the U. S. Steel Corporation; Willis S. N. Waring is associated with the Union Carbide and Carbon Research Laboratories. Manuscript received July 9, 1928.

ture of its transformation to martensite and also of the final destruction of the martensite. This has been possible as a result of the circumstance of a variation in density of the various constituents of steel. Carbides are the most dense, austenite somewhat less dense, and martensite the most voluminous. Ordinary ferrite lies between austenite and martensite as does also the mixture of ferrite and carbide found in annealed steels. Obviously the densest condition which could ever exist in a steel even momentarily would be austenite and undissolved carbides. The density change in the steel is, of course, responsible for the changes in length, but the numerical values of density and a length are not associated in a very simple manner. By measuring the length of an entirely homogeneous rod of metal, its volume changes can be computed accurately; also, if all points of the surface of a sphere receive the same treatment, there may result concentric spherical zones of different character, but still its mean density or volume-change can be estimated by means of a diameter variation. But for almost all other shapes, a single measurement of length alone may not be employed to estimate volume changes, due to the fact that the proportions of constituents will vary along the different parameters chosen. However, in a reasonably homogeneous bar whose length is several times its diameter, the changes will always be in the same algebraic direction as the mean volume-change. This circumstance, if considered for each case, need cause no ambiguity.

The authors have believed that the volume changes in connection with the study of the formation of martensite from austenite during the quenching operation is also significant, just as have been such measurements during tempering. Scott¹ has contributed valuable information of this character with a mathematical discussion. Similarly, the length-change resulting from liquid air treatment should also yield some knowledge of the mode of this action to change austenite to martensite.

THE METHOD

Bars of the annealed steels with spheroidized carbides were employed for all the tests. The size was one-half inch round, and

¹Origin of Quenching Cracks, by Howard Scott. Scientific Paper No. 513, U. S. Bureau of Standards.

the length was always in excess of six times the diameter. The length of steel in this condition is regarded as "normal", i.e., with zero expansion and zero contraction. All changes in length, as a result of quenching, tempering, and liquid air treatments are considered and reported as being plus or minus this normal length. The entire report is in terms of thousandths of an inch (plus or minus) per inch of annealed steel at room temperature 68 degrees Fahr. (20 degrees Cent.). The ease of restoring a steel to this normal condition, and the fact that commercial bars of tool steel are so consistently in this state, led to the choice of this system.

The apparatus for securing data for the length-time curves during quenching consists merely of a small, rigid frame holding the spindle of a Federal dial gage against the end of the heated steel. In the particular form used, the two side bars were of invar metal, with both lower and upper cross-bars of copper. In the lower cross-bar, an invar stud was inserted which projected upward into a depression in the lower end of the specimen. The upper cross-bar was drilled to hold the dial gage. A special long spindle, or "feeler", was put on the dial gage. This spindle likewise made contact with the specimen by resting in a depression in the upper end of the specimen.

As a preliminary attack upon the problem, a hollow cylinder of a high-manganese, high-chromium steel was chosen, which possessed some air-hardening characteristics. Thus the behavior of the equipment design could be observed without the complication of thrusting the frame into the quenching medium. In this case, carbon blocks with parallel sides were placed above and below the hollow cylinder to prevent excessive end loss of heat. The results showed that the specimen in cooling contracted to less than its original length before expanding to several thousandths more during the air hardening. When it was found that satisfactory measurements could actually be made in this manner, the dial and frame combination was adapted to the form described above and provision made for rapid recording of the dial readings when the specimen and holder should be plunged into the quenching bath.

For this purpose, a moving picture camera was utilized. Since only a small amount of film was required for a single quench, the small, inexpensive "Sept" machine was used. Whenever the

length was changing rapidly, the camera was allowed to photograph at full speed—sixteen pictures per second. When the final expansion was occurring, frequent single exposures were made. Later, an exposure every ten seconds is quite ample. Indeed, the film may contain the entire record by snapping the camera every hour at the last. A clock with a large second hand making a full revolution per minute was photographed simultaneously with the dial. By this check, it was found that in four or five seconds the camera had taken an exact sixteen pictures per second within an error of two or three exposures. The clock is indispensable, of course, for the longer intervals. Fig. 1 shows a strip of film wherein the frame is being lowered into the quenching bath and another wherein the pointer is moving rapidly over the dial during contraction.

It should be mentioned that a technique was developed for making these quenches before the camera with a minimum loss of time for transferring the specimens from the controlled furnace to the quenching bath. Usually only three seconds were required to place the specimen in the quenching frame and note the hot length, and not more than two seconds more were required before the camera could begin recording the dial readings during the quench.

For the figures on the length of the steel bars at tempering temperatures, the same dial and frame were again used. The piece was taken from the tempering bath and placed in the frame as quickly as possible at intervals during tempering. The rate of contraction at these low temperatures during the time of reading was so slight as to be negligible. All room temperature readings on the steels after any operation were made in the usual manner.

For the liquid air study, it was desired to check the length changes and hardness measurements with a few magnetic determinations. Hence adequately long bars of square cross section were used. In this case, half-inch squares, ten and one-half inches long, were employed. A special long support was used in the original Federal equipment to accommodate the long bars. In both steels the warping was so slight as to be negligible although some difficulty with warping was encountered with carbon steel quenched in water, in work not reported here.

The inherent errors and other shortcomings of the investigation are discussed below, following the results.

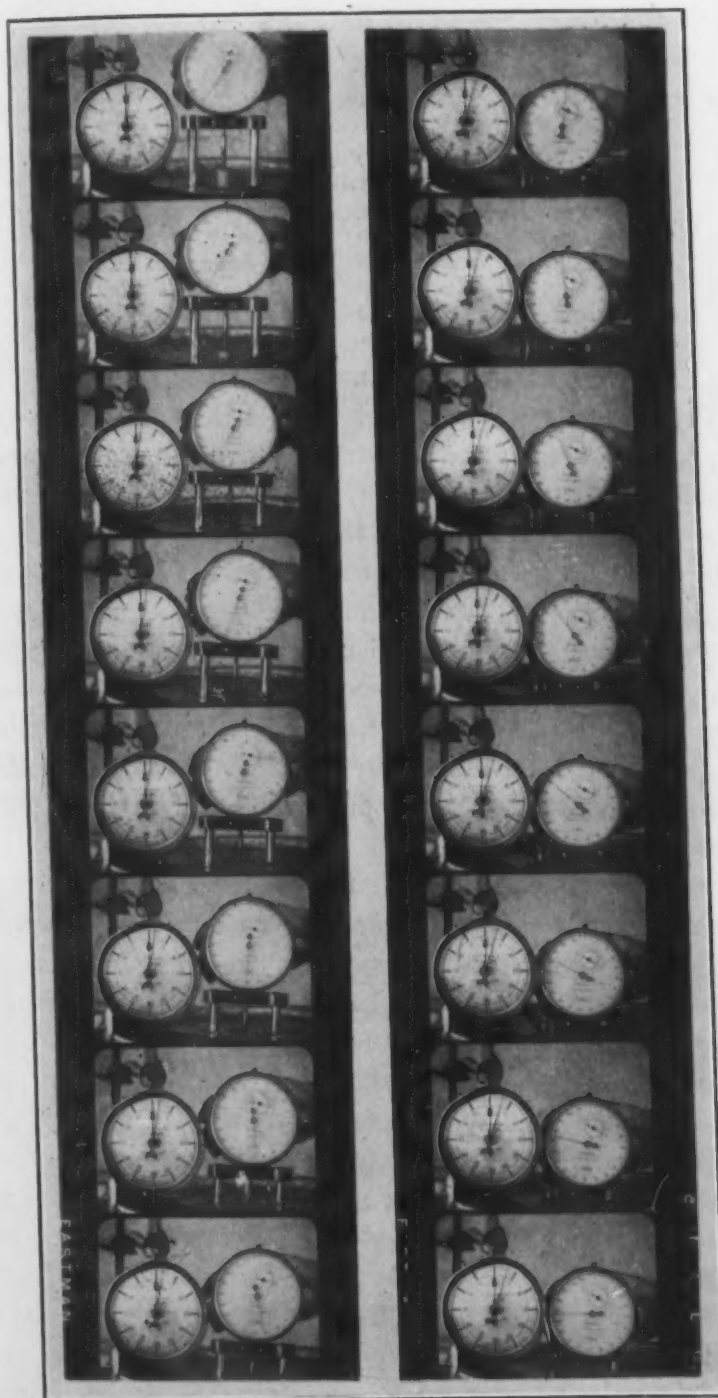


Fig. 1—Prints from Two Strips of Film—One Showing the Quenching Frame with Specimen in Position Just Sinking Into the Bath and the Other Illustrating the Movement of the Dial Gage Needle During Rapid Contraction.

THE RESULTS

The two steels employed showed the following analyses:

	Oil Hardening Steel Per Cent	Stainless Steel Per Cent
Carbon	0.82	0.30
Manganese	1.65	0.14
Chromium	0.03	12.78
Silicon	0.20	0.20
Vanadium	0.00	0.00

Figs. 2 and 3 show the ordinary expansion curves of the two steels. These data were obtained from a dilatometric outfit reading time, specimen temperature, and dial. Both steels were heated and cooled slowly. The die steel, it will be observed, has a high coefficient of expansion both in the ferritic and austenitic condition, with a marked shrinkage occurring at 1360 degrees Fahr. (740 degrees Cent.), at which temperature the material rapidly becomes austenitic. The reversed transformation occurs upon cooling, with very strong recalescence, some hundred degrees lower. It may be seen that for a short time after being heated above the austenite point, the steel is actually more dense than normal austenite. This is probably due to the persistence for a time of the very dense carbide particles.

The stainless steel, due both to lower carbon content as well as high chromium, shows a lower coefficient of expansion. The change from ferrite to austenite occurs at about 1515 degrees Fahr. (825 degrees Cent.). Upon cooling, even with the furnace, the austenite persists down to between 480 and 570 degrees Fahr. (250 and 300 degrees Cent.). Probably the austenite is not entirely pure down to such a low temperature, but at least it persists largely. An interesting effect is noted when expansion does take place; the cooling curve reveals a peculiar trend which the authors have verified by twice repeating the test, but cannot definitely explain. The very rapid expansion after fairly constant length has obtained near room temperature may be due to the formation of a small amount of martensite after only a little austenite remains. These two charts may be used to ascertain the approximate temperature corresponding to any particular length of specimen prior to quenching.

The data were obtained by calibrating the dilatometric appar-

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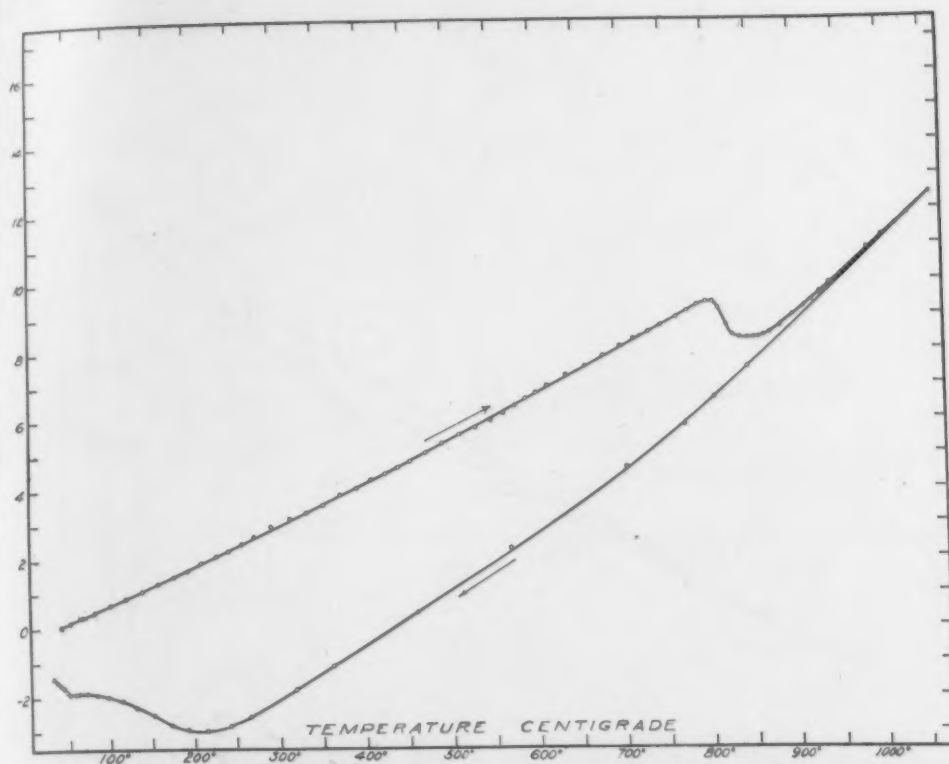


Fig. 2—Length-temperature Curve for Stainless Steel Very Slowly Heated and Cooled. Note Lower Temperature of Transformation Upon Cooling. Ordinate is in Thousandths of an Inch Per Inch Change from Annealed Length at Room Temperature.

atus in terms of a material accurately investigated for linear expansion at the Bureau of Standards. The material was a rustless iron of low carbon content. This method provides an over-all calibration which covers any individual peculiarities of the particular machine used.

Fig. 4 shows in detail the type of results obtained by the method. Three steels, as indicated, were quenched in water with widely varying results. The curve from the carbon steel is merely introduced to show the possible variations in steels, but its origin and analysis are not known. The stainless steel quenched from about 2010 degrees Fahr. (1100 degrees Cent.) has a shorter initial hot length than the others, due to its comparatively low temperature coefficient of expansion. In all cases stainless steel quenches relatively rapidly in any medium. In water, it cooled probably in the vicinity of 1110 degrees Fahr. (600 degrees Cent.) in 2 seconds. Presumably the piece had the mean temperature of about 660 degrees Fahr. (350 degrees Cent.) when the austenite-mar-

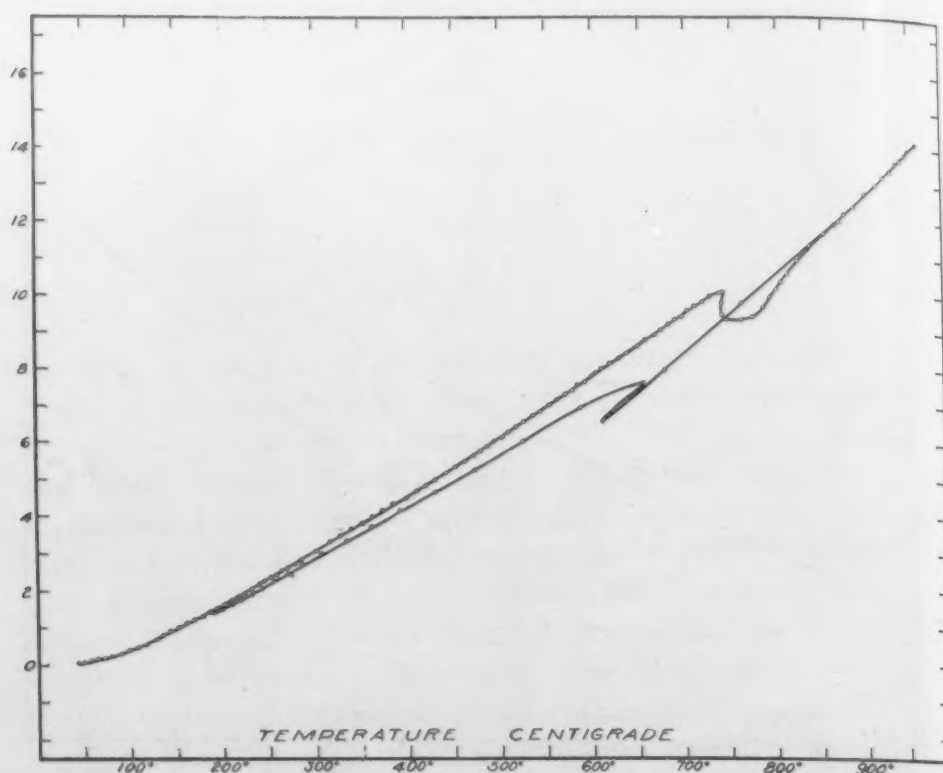


Fig. 3—Length-temperature Curve for the Oil-hardening Die Steel Slowly Heated and Cooled. Note Lower Temperature of Transformation Upon Cooling. Ordinate is in Thousandths of an Inch Per Inch Change from Annealed Length at Room Temperature.

tensite change was proceeding with fair velocity. The outer surface of metal was doubtless much cooler than this. The austenite temperature-contraction period lasts about $2\frac{1}{2}$ seconds, and in the following 4 seconds the expansion of about 0.002 inch occurs. The small gradual contraction which follows may be due to the further temperature contraction of the steel, or more improbably to the decomposition of martensite already formed.

The oil-hardening die steel has much greater length as heated ready for quenching. Usually, its length is about 0.002 inch longer (per inch) at 1830 degrees Fahr. (1000 degrees Cent.) than the stainless steel at 2010 degrees Fahr. (1100 degrees Cent.). It quenches more slowly in water than stainless steel—in the ratio of about 1 to 3. Its contraction does not continue as far as that of stainless steel, and the expansion accompanying the austenite-martensite change persists for a long time and amounts to almost 0.004 inch per inch. It seems characteristic of the oil-hardening

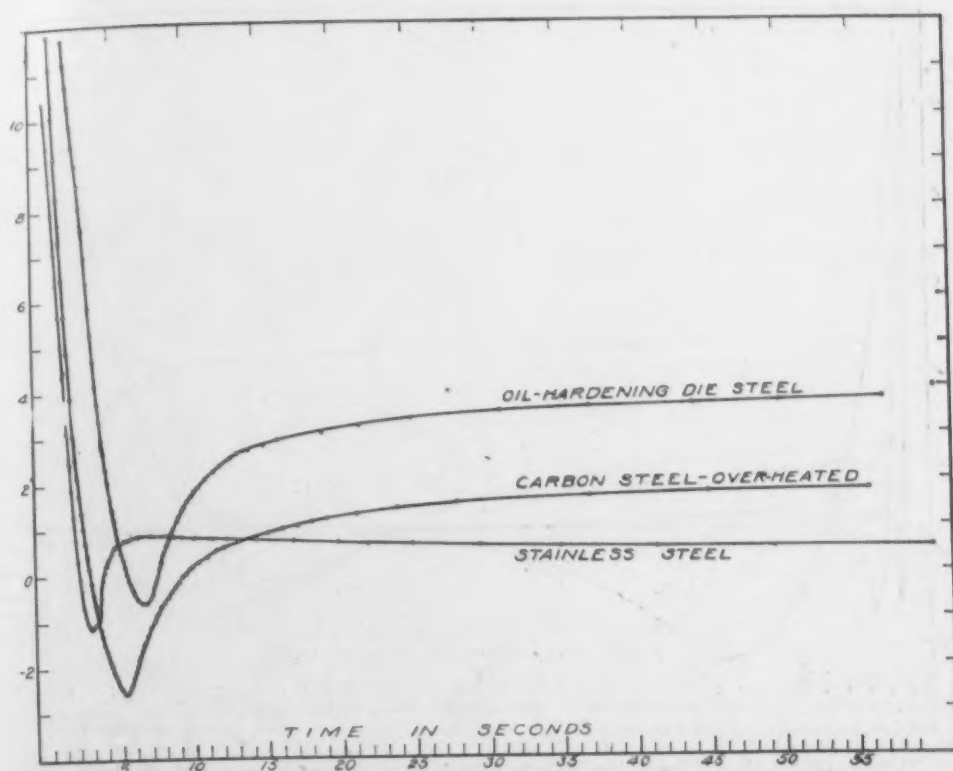


Fig. 4—Length-time Curves of Three Steels During Water Quench. Ordinate is in Thousandths of an Inch Per Inch Change from Annealed Length. Each Circle Represents an Actual Measurement.

steel to show no final contraction at room temperature.

Fig. 5 shows the characteristic length-time curves for the stainless steel when heated to 2010 degrees Fahr. (1100 degrees Cent.) and cooled in water, oil, and air. The oil quench is about five times as slow in lowering the temperature as the water quench, and the expansion takes place also much more slowly during the formation of martensite. In free air, the cooling is probably about one hundred times as slow as in water. With air cooling, the shrinkage is much more marked than with the quenches into liquid, but the final length is about the same. It should be noted that in the chart, the scale of the time for the liquid quenches is ten times as extended as for the air cool.

Fig. 6 shows the length-time curves for the cooling of the oil-hardening die steel from about 1830 degrees Fahr. (1000 degrees Cent.). The rate of cooling is about 212 degrees Fahr. (100 degrees Cent.) per second in water, and in oil about one-half this amount. With this steel, the oil quench causes a much greater

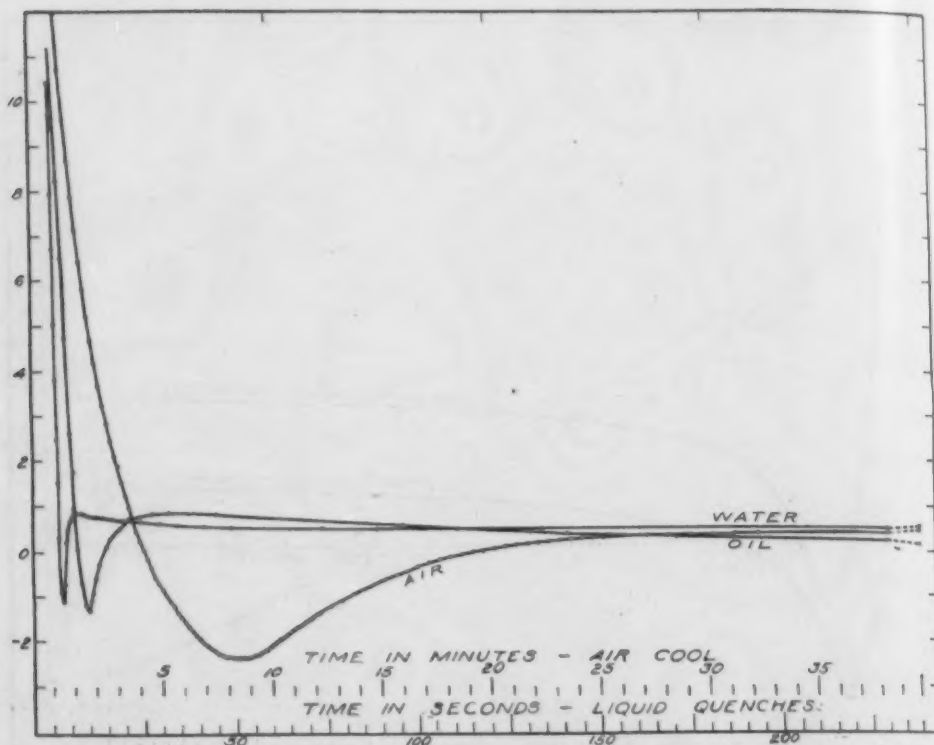


Fig. 5—Length-time Curves for Stainless Steel as Quenched in Oil and Water and as Cooled in Free Air. Ordinate is in Thousandths of an Inch Per Inch Change from Annealed Length. Each Circle Represents an Actual Measurement.

shrinkage to take place and a much smaller subsequent length than the water quench. The air cool is about thirty times as slow as the oil quench and causes less contraction and about the same expansion. The outstanding occurrence here is the great difference in axial length after the lapse of half a minute or a minute between the oil and water-quenched specimens. The difference is several times greater than observed for the stainless steel.

The quenching temperature causes a great change in the contours of the curves. For example, one specimen of the oil-hardening die steel quenched into water from a temperature in excess of 1940 degrees Fahr. (1060 degrees Cent.) showed shrinkage of over 0.002 inch before expansion. A specimen of stainless steel quenched from a temperature of about 2085 degrees Fahr. (1140 degrees Cent.) into oil developed a considerably delayed expansion after shrinking about 0.002 inch. Elevated temperature seems to cause the shrinkage of the water quench to resemble that of the oil quench in the case of these alloy steels. In Fig. 7 are shown

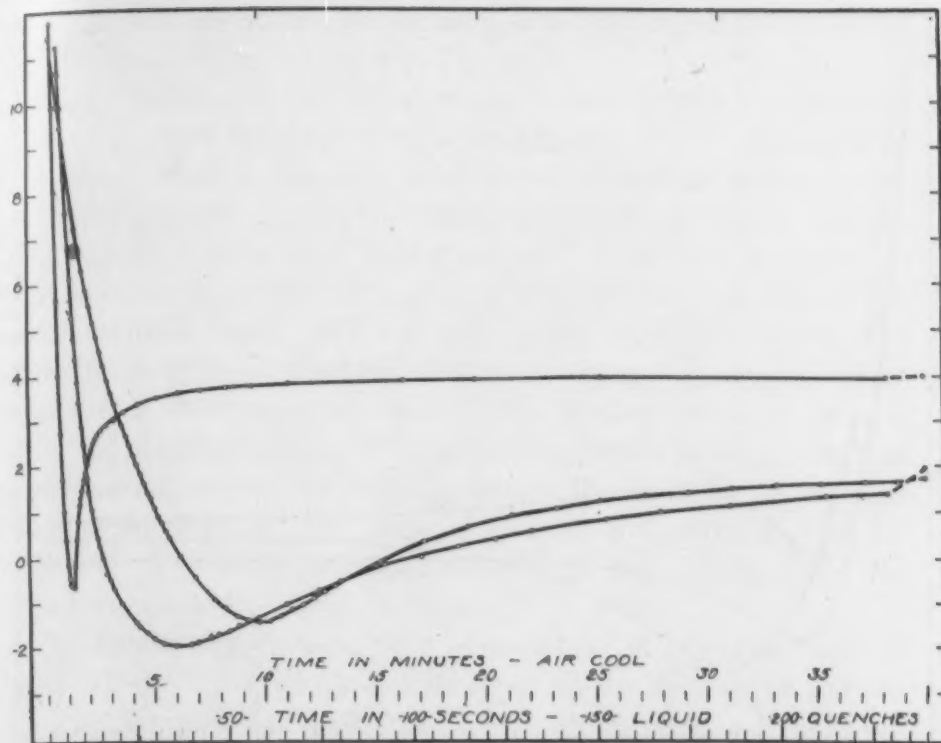


Fig. 6—Length-time Curves for the Oil-hardening Die Steel as Quenched in Oil and Water and as Cooled in Free Air. Ordinate is in Thousandths of an Inch Per Inch Change from Annealed Length. Each Circle Represents an Actual Measurement. Upper Curve Water Quenched, Middle Curve Air Cooled, Lower Curve Oil Quenched.

three length-time curves of stainless steel, all air-cooled but from different temperatures. The tendency for greater shrinkage with higher quenching temperature is clearly indicated. This greater contraction occurs in spite of the fact that the shrinkage rates are nearly the same for all three temperatures. It therefore probably is caused by greater carbide solution at the higher temperatures. In all these curves, there is a possible vertical displacement error of plus or minus 0.0003 inch, due to oxidation of the metal. No precautions were taken to avoid it. If the contacts with the bar were on oxide flakes, the length is recorded too great—otherwise it is too short.

DISCUSSION OF RESULTS

1. For stainless steel, the quenching rates for water, oil, and air are about in the ratio of 100, 25, and 1. For the oil-hardening steel they have a somewhat different ratio—perhaps 100, 40, and

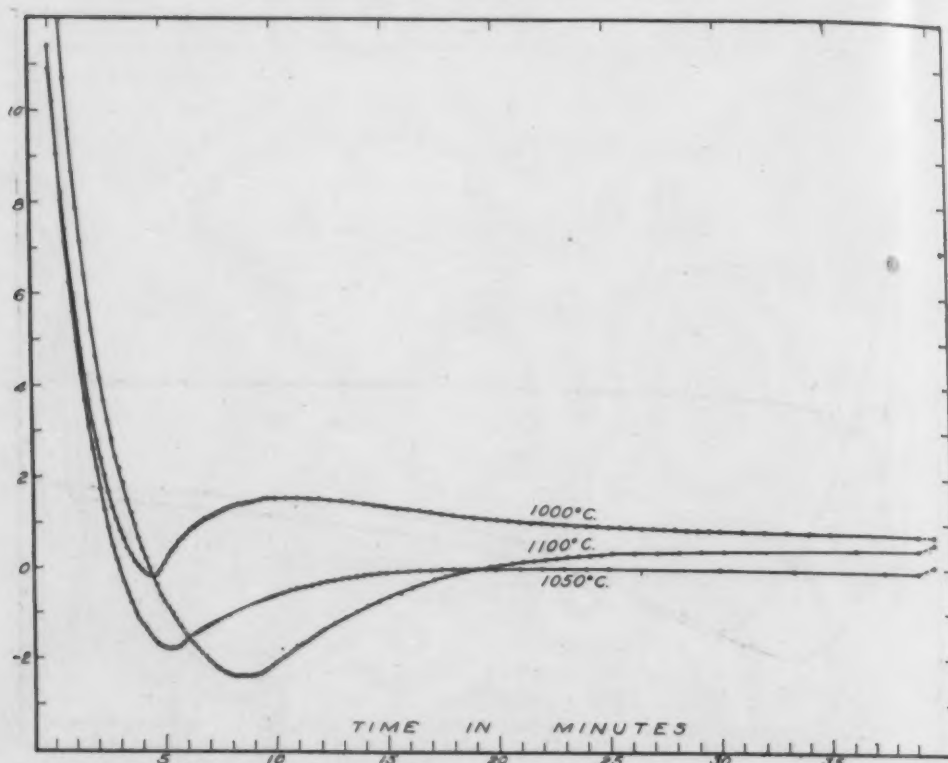


Fig. 7—Length-time Curves for Stainless Steel Air-cooled from 1100, 1050 and 1000 Degrees Cent. Ordinate is in Thousandths of an Inch Per Inch Change from Annealed Length. Each Circle Represents an Actual Measurement.

2. Stainless steel quenches much more rapidly, computed from axial contraction of the austenite, than the die steel, due probably to the hard, adherent scale which offers less effective insulation than the more voluminous loose scale of the die steel. In water quenches particularly, the looser scale may well trap an envelope of water vapor which is effective as an insulating material. In some of the curves plotted, the point at which the steam envelope was penetrated by the quenching water could be discovered by an abrupt increase in cooling rate.

2. There is an outstanding characteristic of high quenching temperatures to cause contraction to a greater extent than the lower quenches. This may be caused in most steels by the more complete solution of the carbides, thus forming an austenite richer in alloying elements and more persistent than otherwise. In other cases, where the steel is completely austenitic in any event, the effect is probably to flatten out the lower part of the ordinary

length-temperature curve, which, as will be developed later, would lessen stresses within the metal.

3. In every case, the rapid water quench causes the contraction to stop when the axial length is only one or two thousandths below zero. Milder quenches cause greater original contractions, and invariably the greatest subsequent length is caused by the rapid quench. This rule seems to hold from the most rapid quenches down to a very slow cooling over an hour or two in the case of stainless steel. Beyond this point, with still more slow cooling in the furnace, the temperature of expansion (due to transformation of the austenite) rises. For the die steel, a rate of cooling corresponding to one hour from original heat to point of transformation causes the transformation to occur in the vicinity of 1110 degrees Fahr. (600 degrees Cent.)—far above that of the oil quench. But more rapid quenches than this again cause the original shrinkage to lessen greatly.

To explain this circumstance of a certain intermediate rate of cooling which causes the austenite in steels to persist during the cooling to the greatest contraction, we may develop a hypothesis. In general, the greatest under-cooling of a phase may be caused by the most rapid quench. As an example—under-cooled liquid metals wherein no stresses can exist are obtained by high rates of cooling. This condition exists here also as far as the very slow rates of cooling are concerned, but the condition changes at a definite rate of cooling and thereafter the more rapid quench hastens the change from austenite to martensite. If the austenite-martensite change involved no volume change, it is likely that austenite would always be preserved most effectively by the rapid quench.

That martensite is produced more abundantly by a water quench, and austenite preserved by oil quenching in many steels has been shown by Mathews and others, and is here again suggested by the greater expansion attained in the water-quenched die steel. The stainless steel offers a special case to be discussed below. One of the authors has already proposed a theory to explain this condition and the present evidence seems to offer some corroboration.

The outstanding difference, so far as the instantaneous condition of the metal is concerned, between a rapid water quench and

a milder oil quench lies in the slope of the thermal gradient from inside to surface. Thus in the water quench, the austenite near the surface is already in considerable tension, while the center is still elongated by its elevated temperature. Since the austenite-martensite change is one involving increase in volume, this outside shell will change the more quickly the greater the tensional stresses existing within it tending to increase its volume. Therefore in rapid quenches, the outside may begin the transformation before the interior has contracted very much. Immediately the outer shell has expanded to form martensite, we have ideal conditions for the entire mass to transform without much further shrinkage. The outer shell now exerts an expanding force upon the austenitic interior immediately inside, as it cools further, and its transformation is thereby accelerated. This accelerating action is a function, obviously, of the gradient; in the severe quenches, the expansion of the exterior zones can occur when the interior zones are still at a temperature of active molecular mobility. In milder quenches, the gradient is less, and the austenite is more nearly at the same temperature throughout when the transformation takes place, and at a much lower temperature, at which austenite changes more slowly to martensite. Therefore, the outside shell does not expand abruptly far ahead of the interior to accelerate the decomposition of austenite. As a result, some of the austenite reaches room temperature unchanged.

With sufficiently slow rates of cooling—as in annealing—there is adequate time for the austenite-ferrite change to take place at temperatures where the action is fairly rapid and grain growth prevents martensite formation. At some intermediate rate, austenite will reach a minimum temperature prior to decomposition. If these suggestions are actually correct, the maximum amount of austenite would be preserved by a quench which would just not permit an outer zone of martensite to form before the interior had reached a temperature at which austenite responds to the accelerating action of mild tension to cause transformation.

Whether or not this hypothesis is correct, the curves show that the idea of water quenches preserving less austenite is well corroborated in length effects, and it seems very certain either that the mean temperature of this transformation is higher in the case of the rapid water quench or that the rapid quench actually per-

manently extends the interior of the bar by its early outer expansion.

The stainless steel seems to behave in somewhat different manner. It possesses a number of unique properties. The austenite of stainless steel is nearly saturated with alloying elements, and is accordingly a sluggish material so far as transformation is concerned. Austenite is preserved with remarkably slow cooling, and such preserved austenite requires a high temperature for decomposition by reheating. And considerable time also is required except at temperatures near the critical. The martensite of stainless steel is never very hard, and would not be able to transfer high stresses. At room temperature, the difference in density between austenite and martensite in stainless steel seems also to be rather less than in other steels. Furthermore, it is a fact that the surface hardness of stainless steel is less as water quenched than when quenched in oil. Here apparently is a case wherein the accelerating action of an outside layer of martensite, as suggested above, does not operate so strongly as in other steels. Below, in connection with the liquid air study, the hardness of stainless steel will be discussed further. At any rate, the failure of stainless steel to show strong expansion upon quenching is probably related in one way or another to its softness.

The reader is urged, if interested, to study the stress analyses of quenched steel provided by Scott² and Hoyt³ in their papers.

LENGTH CHANGES AND OTHER PHENOMENA ACCOMPANYING LIQUID AIR TREATMENT

The authors, not feeling at all certain that stresses played no major part in the hardening of steels by quenching, have also considered the possible effect of the stresses set up within a steel when cooled to the temperature of liquid air. It is well known that when a steel containing austenite is introduced into liquid air, the austenite is destroyed. Even wholly austenitic steels apparently are at least partially changed to what appears to be martensite. One of the authors suggested that the change was possibly due to the stresses set up by the steep thermal gradient in-

²Loc. cit.

³Stresses in Quenched and Tempered Steels, TRANSACTIONS, American Society for Steel Treating, Vol. 11, April, 1927, page 509.

duced by the immersion. The sudden removal of heat from the piece would develop high tensional stresses in the outside zone of the specimen which might perhaps be sufficient to cause martensitization by elongation. To test this hypothesis, one has only to cool the specimen so gradually as to eliminate any appreciable thermal gradient within the bar and ascertain whether or not the austenite had decomposed under these conditions. The assumption was made that previous investigators had plunged their specimens into the liquid air. A preliminary experiment was not decisive, due to the small size of specimen and lack of sufficient liquid air.

EXPERIMENTATION

Dr. S. L. Hoyt of the General Electric Research Laboratories kindly offered to co-operate in this test, and accordingly the experimentation was performed at the General Electric Laboratories with equipment available there and with the assistance of several of the staff.

In order to check the length-change and hardness effects with some magnetic measurements, bars $10\frac{1}{2}$ inches in length were prepared with parallel ends from both steels under consideration. They were first quenched in oil at a temperature to preserve a large amount of austenite. Their original length and length after hardening was measured, and in the quenched state they were allowed to age for about three weeks at room temperature to permit the low temperature precipitation of carbide, if any should be formed in these steels. The magnetic measurements were then made and the slow cooling to liquid air temperature brought about.

This slow drop in temperature was accomplished by surrounding the steel bars by heavy insulation for the immersion into liquid air. The bars were wrapped in paper and then placed in a length of four-inch pipe. This left a space of about an inch which was packed with feather down. At the ends, even more space existed between the pipe caps and the ends of the bars. It was estimated that some four or five hours would be required to bring the bars to within five degrees of the liquid air temperature. The caps were screwed on tightly with proper white lead cement for a seal. This container was kept covered with liquid air for about six hours. Several hours more were required to evaporate all the liquid air,

and sixteen hours after immersion, the pipe caps were removed and a special low temperature thermometer introduced carefully alongside the bars with the least possible disturbance of the insulation. About 200 minutes were required to raise the temperature of the bars from -76 to 32 degrees Fahr. (-60 to 0 degrees Cent.). This rate of transfer of heat through the insulation indicates that the cooling rate was also satisfactory, inasmuch as it was probably still slower. When the bars were well above 32 degrees Fahr. (0 degrees Cent.), they were removed from the insulation and allowed to arrive at room temperature. Hardness, length-change and magnetic properties were again measured. The bars were again cooled, this time quickly, to liquid air temperature by direct immersion. Again the bars were tested for changes in hardness, length and magnetic properties. The first refrigeration caused considerable change and the second substantially none, as will be seen in the following tables. Each steel was represented by two bars (A and B) in order to check the consistency of the results.

THE RESULTS

The results for the die steel are tabulated below. The system already employed for reporting length changes is again used—annealed length is taken as zero.

HARDNESS CHANGES			
(Average of 10 Determinations)			
Annealed	Quenched and Aged	First Liquid Air	Second Liquid Air
A. 20.9	61.3	65.4	65.2
B. 20.9	61.5	65.6	66.1
LENGTH CHANGES PER INCH			
Annealed	Quenched and Aged	First Liquid Air	Second Liquid Air
A. 0	+ .00100 in.	+ .00333	+ .00330
B. 0	+ .00092 in.	+ .00325	+ .00321
MAGNETIC. (SATURATION, $H = 2500$)			
Values of B ($B = \beta + H$)			
Quenched and Aged	First Liquid Air		Second Liquid Air
A. 14800	19900		19800
B. 14500	19800		19850
MAGNETIC. HYSTERESIS			
(Closed circuit Peak $H = 1000$) Values of $\beta_r =$ Residual			
Quenched and Aged	First Liquid Air		Second Liquid Air
A. 3950	7200		7150
B. 3900	7100		7200

MAGNETIC			
		Values of H_c , Coercive Force	
Quenched and Aged		First Liquid Air	Second Liquid Air
A.	51.0	52.4	52.0
B.	48.0	52.1	52.0

MAGNETIC			
		Residual (Open Circuit) Values of β_r 1	
Quenched and Aged		First Liquid Air	Second Liquid Air
A.	1530	2260	2262
B.	1515	2275	2275

The results for the stainless steel follow:

HARDNESS CHANGES			
Annealed		Quenched and Aged	First Liquid Air
A.	18.7	53.0	53.0
B.	18.7	53.5	53.7
			Second Liquid Air
			53.0
			54.0

LENGTH CHANGES PER INCH			
Annealed		Quenched and Aged	First Liquid Air
A.	0	-.00077	-.00011
B.	0	-.00076	+.00021
			Second Liquid Air
			-.00011
			+.00019

MAGNETIC			
		Saturation ($H = 2500$) Values of B ($B = \beta + H$)	
Quenched and Aged		First Liquid Air	Second Liquid Air
A.	13600	15900	16000
B.	13500	16150	16100

MAGNETIC			
		Hysteresis (Closed Circuit, Peak $H = 1000$) Values of $\beta_r =$ Residual	
Quenched and Aged		First Liquid Air	Second Liquid Air
A.	4350	5350	5500
B.	4300	5500	5600

MAGNETIC			
		Values of H_c , Coercive Force	
Quenched and Aged		First Liquid Air	Second Liquid Air
A.	76.0	77.4	77.6
B.	74.0	74.8	76.6

MAGNETIC			
		Residual (Open Circuit) Values of β_r 1	
Quenched and Aged		First Liquid Air	Second Liquid Air
A.	53.0	53.0	53.0
B.	53.5	53.7	54.0

DISCUSSION OF RESULTS

The results point clearly to the conclusion that whatever changes are brought about by extremely low temperatures are not caused by a steep thermal gradient within the metal and the accompanying stresses. The uniform low temperature is apparently sufficient to destroy the austenite, and further liquid air

treatment accomplishes little or nothing. The increase in permeability and the expansion indicates that austenite is removed, while the hardness increase and the other magnetic changes indicate the formation of martensite. In the case of the die steel, the evidence points conclusively to the removal of practically all the austenite. Heating the bars to the tempering temperature at which any austenite should be destroyed produced a rather large contraction (-0.0015 In.) instead of any expansion, a significant though not conclusive point.

In the case of the stainless steel, the results are less conclusive, although in general they parallel the changes in the die steel in trend. Presumably much austenite was retained after the quench and some of it was transformed by the first liquid air treatment. Into what sort of constituent it transformed, is not clear, since the hardness remained constant. One of the authors has previously pointed out that high-chromium martensite is never very hard, and that probably its hardness is due chiefly to the carbide precipitation. A mixture of austenite and martensite in stainless steel is seemingly nearly as hard as the nearly pure martensite. Possibly in such a rich solid solution as the austenite of stainless steel, the transformation always begins from too few nuclei to produce the fine-grain type of martensitic hardness to the extent found in other steels.

LENGTH CHANGES DUE TO TEMPERING

A large number of data upon the changes in length of steel bars during tempering have been made available through the investigations of Grossmann and others. In general, all these series have revealed a very definite behavior, so that such length changes can be relied upon to constitute a sort of test for the preservation of austenite in the quenched steel and a test for the pseudo-stability of such austenite. The successively higher tempering treatments always produce at first a shrinkage of the bar. It is universally conceded that this evidences the precipitation of carbide particles, leaving the preserved austenite unchanged. At some temperature which varies with the amount and kind of alloying elements, the tempering brings about expansion of the bar. This expansion is regarded as being caused by the release of the austen-

ite to form martensite. The X-rays have in several cases shown the disappearance of the austenite phase at the tempering temperature at which the expansion occurred. The carbide precipitation is, of course, a reaction involving time, and the authors have

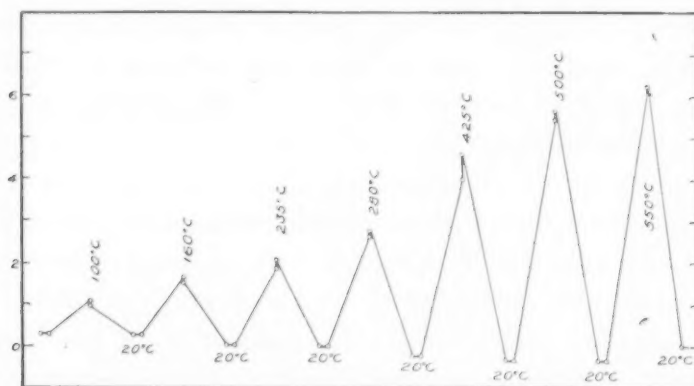


Fig. 8—Length Changes in Stainless Steel During and After Various Tempering Temperatures of One-half Hour Duration. Ordinate is in Thousandths of an Inch Per Inch Change from Annealed Length.

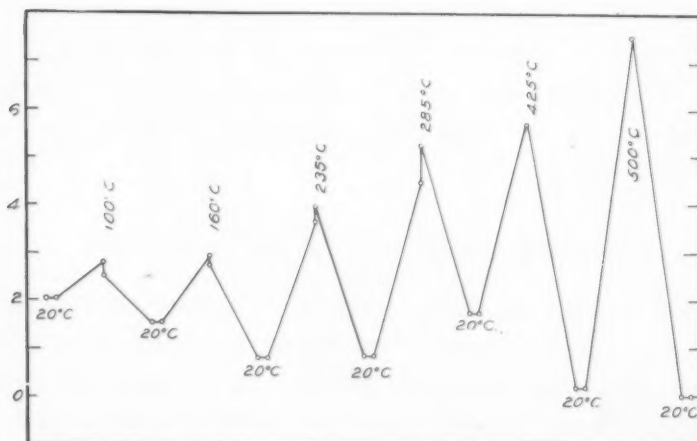


Fig. 9—Length Changes in the Oil-hardening Die Steel During and After Various Tempering Temperatures of One-half Hour Duration. Ordinate is in Thousandths of an Inch Per Inch Change from Annealed Length.

assumed that the destruction of the preserved austenite was a reaction of the same type. However, to check this, some measurements were again made upon these steels in a manner to ascertain whether the expansion occurred continuously and gradually while at the tempering temperature.

Bars of both the die steel and the stainless steel were quenched

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from comparatively high temperature into oil to preserve the austenite copiously. The bars were then tempered in a liquid bath and from time to time during the tempering the length was measured. The cold length was also taken between the half hour tempering treatments at various temperatures.

The charts in Figs. 8 and 9 show the changes in length during the half hour at specified temperatures, and also the room temperature lengths. The usual system is followed in these charts. The annealed length is taken as zero. The charts show how much alteration in length occurred during tempering. The highest temperatures were not supplied by liquid baths, and do not show the detail of length-change.

In view of the results obtained from the liquid air investigation, the authors suggest that the very low temperature austenite-martensite transformation is actually more complex than has been supposed, and the work of other investigators is eagerly awaited.

It may well be that stresses are responsible for the transformation in spite of the proof that a steep thermal gradient is entirely unnecessary. It will be remembered that the rate of expansion and contraction of austenite with temperature is much greater than for iron in the alpha condition. Hence in any steel composed of martensite and austenite, the austenite would tend to be extended by the more slowly contracting ferrite or martensite. At such a temperature -310 degrees Fahr. (-190 degrees Cent.), if the differential expansion between austenite and ferrite continues as at temperatures where it has been measured, the austenite would tend to occupy much less of the total volume of the steel than at room temperature. The stresses tending to extend the austenite, exerted by the martensite of the mixture, would be a powerful predisposition for the change. And accordingly, steels such as the two employed would not be suited for deciding whether mere temperature alone, or thermal stresses, cause the transformation. The proper material to test the point would be a pure homogeneous austenite. If a quick immersion then caused partial decomposition, while slow cooling to liquid air temperature left the austenite unchanged, the solution for the problem would be at hand. It is hoped that such an experiment will be reported, using either a high nickel steel or a manganese steel of the Hadfield type.

FURTHER WORK

A continuation of this introduction to length-change study could be carried out to decide some of the ambiguities disclosed here. Some suggestions for improving the results and giving them wider application follow.

1. The specimens could be protected against oxidation sufficiently to enormously reduce the probable error by plating the surface. It has been suggested that a copper plate followed by a chromium plate would preserve a more accurate surface for the brief time of heating and quenching.

2. The effect of quenching bath temperature is probably very critical and should be investigated.

3. The time of heating prior to quench is certainly very effective in altering the contour of the curves, especially with steels of composition far from the eutectoid.

4. The length-change characteristics with tempering should be considered for variously quenched steels, to corroborate the austenite concentration. A definite schedule of tempering should be maintained very exactly.

5. Pure austenitic steels, quenched and slowly cooled to liquid air temperature from room temperature, might be studied by hardness, length, and magnetic measurements.

DISCUSSION

Written Discussion: By M. A. Grossmann, Central Alloy Steel Corp., Canton, Ohio.

The authors have developed a new and ingenious method for measuring the length changes which accompany hardening. Their study adds valuable data to the work of Portevin and Garvin who worked with thin wires and that of Scott on bars partially quenched and then cooled in air.

It is believed that some interest may attach to some data secured by the present writer and hitherto unpublished, covering similar phenomena in the hardening of high speed steel. The curves which are shown in Fig. A, were taken on pieces of high speed steel while they were cooling from the hardening temperature. Several circumstances combine to make such data on high speed steel a fairly reliable index of the reactions in the steel during hardening. First, as is well-known, the hardening of high speed steel in small sections is about the same whether the piece be cooled in air or quenched in a cooling liquid such as oil. This makes it possible to employ comparatively slow cooling rates and so have time to note and record individual readings. Second, the volumes at room temperature of high speed steels hardened from

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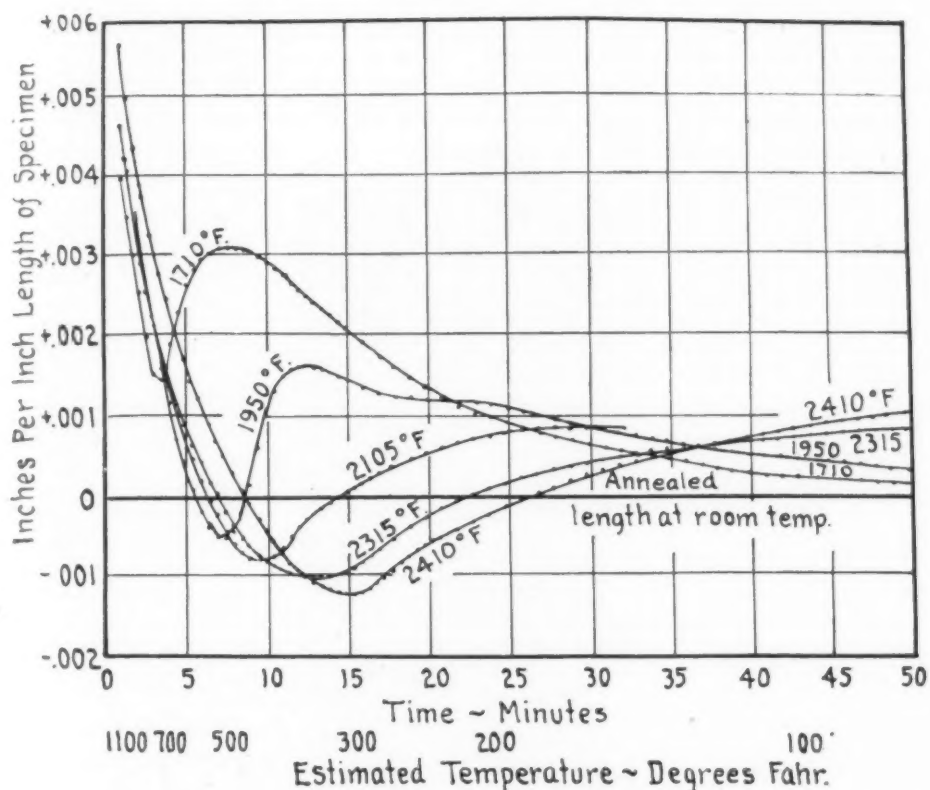


Fig. A—Time-Shrinkage Curves of High Speed Steel Showing Change of Length During the Hardening While High Speed Steel is Being Cooled from the Hardening Temperature. The Hardening Temperature is Indicated on Each Curve. Readings Cover the Interval of Cooling from 1100 degrees Fahr. to Room Temperature.

various temperatures are known fairly accurately in comparison with the annealed condition, such data having been secured for example by the present writer¹ and by E. C. Bain in collaboration with the writer.² In Fig. A volume changes are plotted against time during the cooling. The circumstance that the volume of the steel after hardening is known, makes it possible to place the cooling curves of Fig. A so that their relative volumes during cooling show quite accurately.

The data of Fig. A were taken on pieces of high speed steel of the following composition: carbon, 0.72 per cent; tungsten, 18.0 per cent; chromium, 4.0 per cent; vanadium, 1.0 per cent. The pieces were 1 inch in diameter and 4 inches long. The curves of Fig. A (in which each dot represents a reading) were obtained as follows. The steel was heated in a Globar furnace to the temperature indicated on the curve, then cooled rather quickly to about 1250 degrees Fahr. by dipping momentarily in oil then placed in the dilatometer when the temperature had dropped in air to about 1100 degrees Fahr. The dilatometer is shown in Fig. B.

¹Chemical and Metallurgical Engineering, September 13, 1922, p. 541.

²TRANSACTIONS, American Society for Steel Treating, October, 1924, p. 430.

The curves demonstrate two interesting facts. When the quenching temperature is low such as 1710 degrees Fahr., the transformation to such martensite as is formed is sudden and complete, if one can judge from the subsequent thermal contraction which follows the martensite expansion. The total

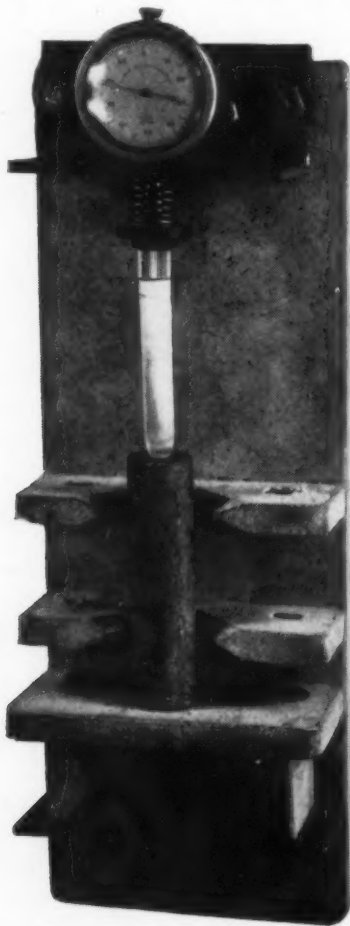


Fig. B—Photograph of the Dilatometer Used in These Experiments.

amount of martensite formed after a low quenching temperature is however comparatively small. As the quenching temperature is raised two effects are noticed, (1) the austenite cools further before transforming to martensite, the austenite being more stable because it has dissolved more alloy and carbon, and (2) the transformation to martensite takes place over a wider range of temperature. At the highest quenching temperatures, the expansion, when once begun, proceeds during the whole cooling period to room temperature and indeed the expansion continues even at room temperature, as was found on the curve for 2410 degrees Fahr., which showed additional expansion of 0.00003-inch twelve hours later.

The change from sudden transformation to gradual transformation indicates the difficulty of locating the transformation points of such steels by

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thermocouple methods alone. It also shows that the volume increase near room temperature is a reliable indication that martensite continues to form over a relatively long period of time down to room temperature.

The shape of the curves also points to the great value inherent in the experimental method devised by Mr. Bain and Mr. Waring. Their method is particularly valuable because the changes are recorded during the actual quenching operation. They make the interesting suggestion that the method be used in finding the true "quenching power" of quenching media, and it would also be of interest to see the method employed on bars of different sizes.

Written Discussion: By Dr. Albert Sauveur, Harvard University, Cambridge, Mass.

The authors are to be congratulated for their skill and ingenuity in conducting some difficult experiments.

I conceive the decomposition of austenite to result from two distinct transformations which may take place nearly simultaneously:

- (1) The transformation of some gamma iron into alpha iron followed immediately by
- (2) The rejection of minute particles of cementite within the newly formed alpha phase, which is thereby converted into troostite.

Rejection of carbide by the alpha phase may be far advanced before the allotropic transformation is completed, a stage being reached when the steel consists of undecomposed austenite and of troostite—the latter constituent having formed along the crystallographic planes of the original austenite, resulting in the well known martensitic type of structure. This structure is retained by rapid cooling. On slow cooling, both the allotropic transformation and the rejection of cementite are complete and the steel converted into an aggregate of iron and cementite.

Some appear to have difficulty in accepting the presence of troostite in hardened (martensitic) steels and still they admit that such steels contain both alpha iron and finely divided particles of cementite, the constitution which they themselves attribute to troostite.

The transformation of gamma into alpha is accompanied by increased volume while, according to general belief, the formation of cementite particles results in decreased volume. From the fact that steel in the martensitic condition is less dense than pearlite or completely transformed steel, it must be concluded that the increased volume resulting from the allotropic transformation exceeds the decrease of volume resulting from the precipitation of carbide particles in the alpha phase. After complete transformation, the steel returns to its original dimensions.

Referring to the decomposition of austenite in liquid air in steels which after slow cooling remain austenitic at room temperature, it never occurred to me that the phenomenon was difficult to explain. In order to preserve a martensitic structure, it is necessary that the decomposition of austenite be delayed until a temperature of some 300 degrees Cent. or lower is reached. With carbon steel this is accomplished by rapid cooling. In air hardening

steel the A_s point is lowered to the required temperature by the special elements present and the steel becomes and remains martensitic on slow cooling. In so called austenitic steel, the transformation point being lowered below room temperature, it is necessary to expose them to these low temperatures in order to bring about austenite decomposition.

The fact that some steels may have their transformation point at 700 degrees Cent., others at 300 degrees Cent., others still at -100 degrees Cent. or lower does not, in my opinion, imply a difference in the cause and mechanism of the transformation. Phenomena occurring at temperatures lower than room temperature should not on that account be considered different in nature from similar phenomena occurring at temperatures exceeding room temperature. From the fact that a metal may melt at 1000 degrees Cent., another at 300 degrees Cent., another still below room temperature, we do not infer that the mechanism of solidification is not the same in every instance. This so called room temperature has no special significance except so far as it may contribute to our comfort or discomfort.

Authors' Reply to Discussion

E. C. BAIN: First of all we would like to say that we are very pleased that this introductory paper should have brought forth discussion and such interesting comment.

Mr. Grossmann's discussion indicates clearly that he has obtained information concerning high speed steel precisely analogous to that which we have endeavored to secure for the two steels just discussed. The completeness of his investigation is such that he might well have made of it a separate paper instead of introducing it in this manner. We are therefore the more deeply appreciative. In view of the air-hardening characteristics of high speed steel he has been able to secure cooling curves of length change without the complication of such a quenching frame as we used.

His thoughtful choice of the precise units for abscissa and ordinate makes comparison with our results very convenient. He finds that the higher the quenching temperature, the longer is the austenite preserved and the more slowly it is decomposed after the specimen has practically reached room temperature. This is in complete accord with our steels which do not exhibit air-hardening characteristics. His results are clear and accurate and there is accordingly little more to be said except to compliment him on the work and again to thank him for offering it as a discussion of our paper.

It may be excused perhaps if we are especially happy that Prof. Sauveur has wished to discuss our introductory paper. In a reply to his interesting comments upon the mode of austenite decomposition we are inclined to mention first the essential agreement of our conception with his. Although our chief differences of opinion probably lie in nomenclature, we do feel inclined to say that our interpretation of some of the vast amount of data available is slightly different—perhaps, more or less fundamentally. If we may presume in the face of Prof. Sauveur's long experience in the study of the austenite-martensite transformation to express these differences of opinion, it would be first mentioned that in the martensite which has not yet age-

hardened there is very little carbide in existence. Thus the martensite in these specimens during the taking of expansion and contraction curves contains the carbon in an unstable alpha iron solid solution. Later such martensite will age by forming some submicroscopic crystallites of Fe_3C . Even then the martensite will not etch with chemical reagents as the somewhat coarser carbide dispersion will indicate troosite. If in freshly quenched martensite carbide has already precipitated the particles are too small to exhibit the properties of regular Fe_3C . Carbon steel martensite ages even at 20 degrees Cent. (75 degrees Fahr.) which as Prof. Sauveur cleverly points out is no particular temperature except a comfortable one.

The other point is that we do not believe the ordinarily designated austenitic steels such as Hadfield's manganese steel and some nickel steels are truly stable austenite at temperatures in the vicinity of room temperature nor even a few hundred degrees above. In the physical chemical sense they are merely undercooled austenite sluggish by virtue of the alloy. Otherwise we should not be able to develop alpha iron in them by prolonged heating at elevated temperature which has often been accomplished in both types. If they were really only truly unstable at temperatures as low as liquid air, then any martensitization accomplished by such refrigeration would be reversed at room temperature. These experiments, it was hoped, might shed some light upon the mechanism of the changes which take place in steel at very low temperatures for certainly the processes are incompletely understood at present.

THE EFFECT OF FURNACE ATMOSPHERES ON STEEL

BY R. G. GUTHRIE

Abstract

The author has conducted fundamental tests with atmospheres commonly met with in the various types of heat treating furnaces, and has chosen a temperature of 1500 degrees Fahr. throughout all the tests as being an average temperature for the heat treatment of carbon steels of about the eutectoid composition. He has attempted to make these preliminary reports as simple and comprehensive as possible by using a series of photomicrographs in which the type of steel, conditions of time, temperature, pressure, velocity, etc., are constant with the only variable being the different simple gases. An additional set of photomicrographs with explanatory notes is incorporated, showing some of the effects of mixing the gases in various proportions.

The chemistry of combustion of gas has been added as an appendix for those caring to delve into this phase of the subject.

This paper is meant to be taken in the light of a progress report on a subject upon which a great deal more work is being done. The summary contains three practical conclusions as a result of the work thus far.

THE effects of various furnace atmospheres on steel are mostly a matter of hearsay which the average furnace user accepts as being obviously the truth. Fundamentally, however, our experiments upon the subject confirm some of the beliefs and upset others. All of our work confirms the fact that a potentially flexible atmosphere is of a great advantage if intelligently used; and that the more flexible the atmosphere the better.

The most common and general effects of furnace atmospheres on steel may be set down as follows:

1. oxidation (scaling)
2. decarburization
3. decarburization and oxidation
4. carburization.

A paper presented before the tenth annual convention of the society, held in Philadelphia, October 8 to 12, 1928. The author, R. G. Guthrie, vice-president of the society, is metallurgist with the People's Gas Light and Coke Company, Chicago. Manuscript received August 7, 1928.

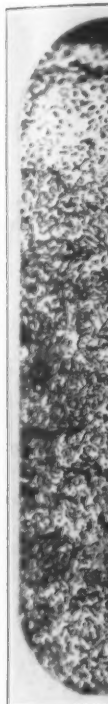


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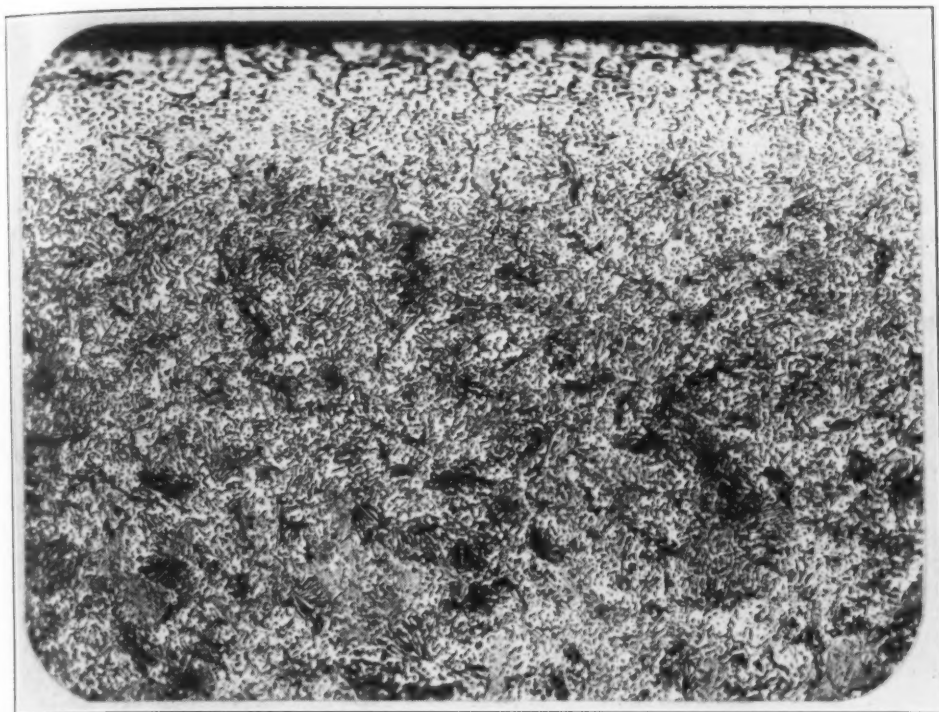


Fig. 1—Photomicrograph of Specimen Heated in Dry Oxygen at 1500 Degrees Fahr. for 2 Hours and Slowly Cooled. $\times 170$.

It is entirely possible to have any of these conditions separately, or even certain combinations of them occurring on a piece of steel. The chemistry of any furnace atmosphere is, at its simplest, a set of complicated reactions. For this reason the chemistry of the combustion of gas is incorporated in this paper, together with tables, as a reference for the reader, but the body of the paper deals with fundamental elements and compounds which in themselves are basically responsible for these phenomena.

A fused silica tube was externally heated for these tests, and samples of a straight carbon steel (0.90 per cent carbon) was used. The photomicrographs are self-explanatory and show the condition of a cross-section of the sample at and adjacent to its outer surface.

A great many tests were made in the tube furnace under known atmospheric conditions. However, the tests conducted with oxygen, carbon dioxide, steam, hydrogen, and normal air, respectively, gave the most interesting and useful results. The conditions under which the tests were run were identical in every case. The steel specimens were all cut from the same bar with the same

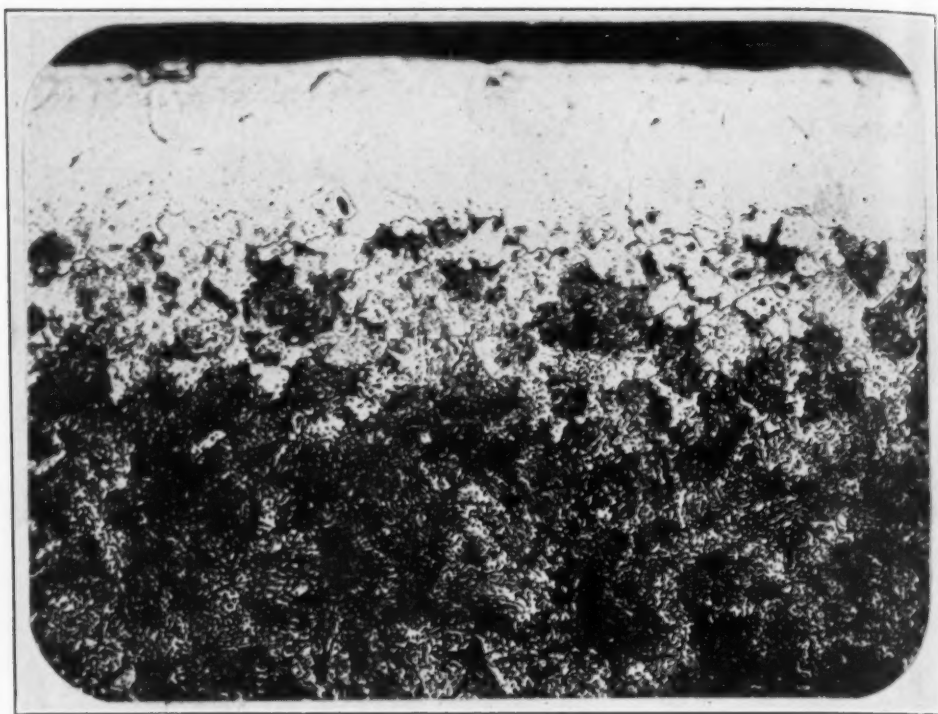


Fig. 2—Photomicrograph of Specimen Heated in Dry Carbon Dioxide at 1500 Degrees Fahr. for 2 Hours and Slowly Cooled. $\times 170$.

amount of surface machined away. All gases except the steam and air were of the highest purity and moisture-free. Each test included two samples heated to 1500 degrees Fahr. and held for two hours, after which time one was removed and quenched in water, the other being slowly cooled in the atmosphere in which it was heated.

CONDITION NUMBER ONE

Samples heated in pure dry oxygen (O_2) show practically no indication of decarburization. (See Fig. 1.) The samples were covered with a thick scale that not only reduced the dimensions of the piece, but blanketed it somewhat in the quench.

CONDITION NUMBER TWO

Samples heated in dry carbon dioxide (CO_2) show decarburization. (See Fig. 2.) Furthermore, they were covered with a thick scale in addition to the decarburized layer.

CONDITION NUMBER THREE

Samples heated in superheated steam (1500 degrees Fahr.)

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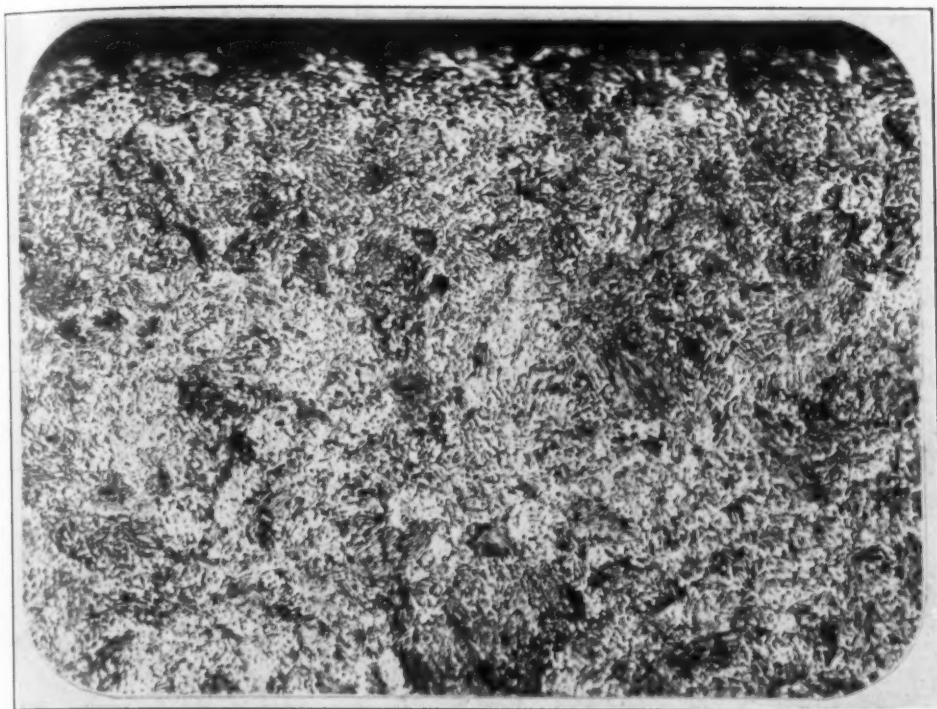


Fig. 3—Photomicrograph of Specimen Heated in Superheated Steam at 1500 Degrees Fahr. for 2 Hours and Slowly Cooled. $\times 170$.

show no decarburization. (See Fig. 3.) They were covered with a double layer of scale, the inner layer adhering very closely and composed of bright, coarse crystals, such as those formed and reported by Guthrie and Wozasek in *TRANSACTIONS, American Society for Steel Treating*, Vol. XII, December, 1927, page 861, Fig. 5.

CONDITION NUMBER FOUR

Samples heated in hydrogen (H_2) show decarburization slightly less complete than in Condition Number Two. (See Fig. 4.) There was no scale on the samples. The reactions for the decarburization of steel with H_2 are very thoroughly given by Sykes in his excellent paper on "Carburization of Steel With Mixtures of Hydrogen and Methane" in *TRANSACTIONS, American Society for Steel Treating*, Vol. XII, November, 1927.

CONDITION NUMBER FIVE

Samples heated in normal air with a relative humidity at

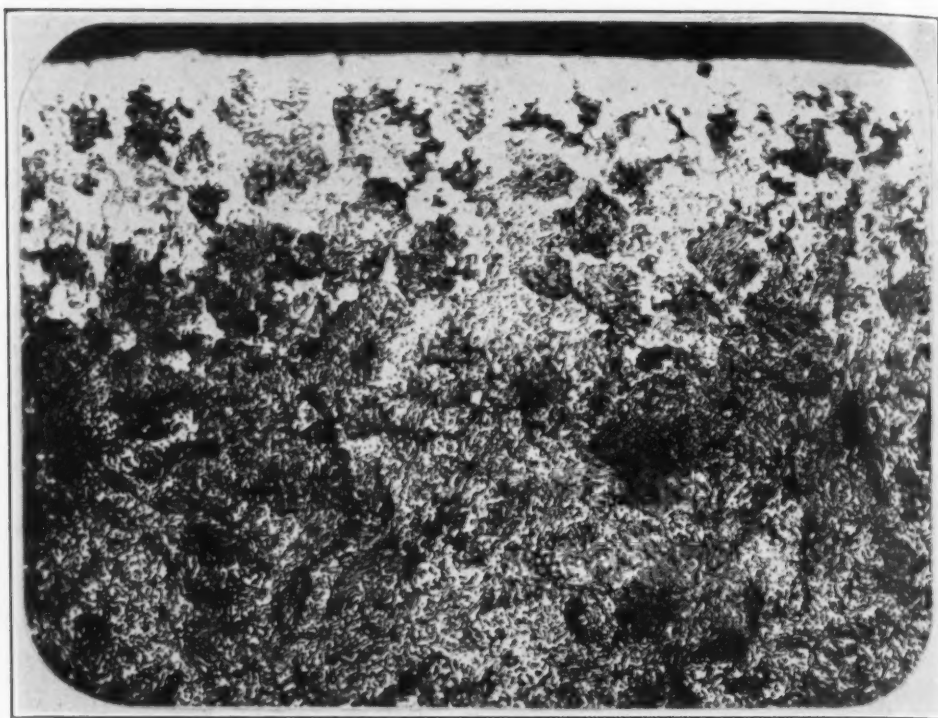


Fig. 4—Photomicrograph of Specimen Heated in Dry Hydrogen at 1500 Degrees Fahr. for 2 Hours and Slowly Cooled. $\times 170$.

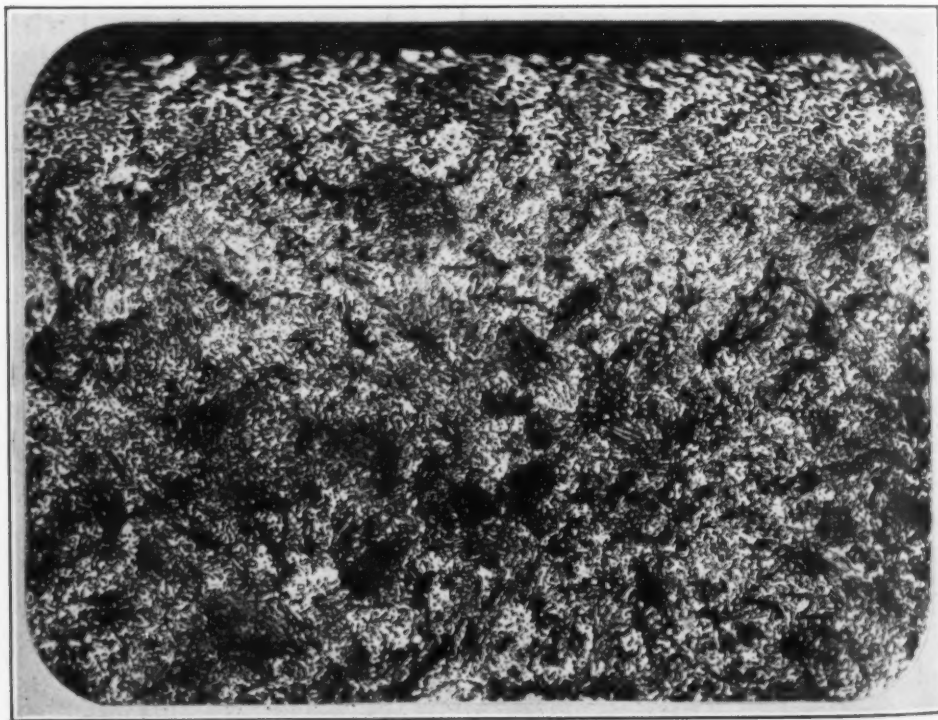


Fig. 5—Photomicrograph of Specimen Heated in Stagnant Air (Relative Moisture of 61.5 Per Cent at 83 Degrees Fahr.) at 1500 Degrees Fahr. for 2 Hours and Slowly Cooled. $\times 170$.

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83 degrees Fahr. of 61.5 per cent show practically no decarburization, but are covered with a heavy scale. (See Fig. 5.)

RESULTS

The information gained from the above is that oxidation is not necessarily accompanied by decarburization; that the one is not a function of the other.

Carbon dioxide alone is a very rapid scaler (oxidizer of iron) as well as a very active decarburizer.

Steam is an active scaler (oxidizer of iron) but not a decarburizer.

Hydrogen alone is an active decarburizer but does not scale or oxidize the surface.

Normal still air alone is an active scaler (oxidizer of iron) but not a decarburizer at this temperature, 1500 degrees. Fahr.

It is a well known fact that carbon monoxide, methane, illuminants, and other hydrocarbons, are carburizers. It has been found, however, that water vapor in combination with the above carburizing gases acts as a deterrent to their carburizing action, and as has been shown, water is an oxidizer first of the iron and, second, of any available carbon. It, therefore, becomes apparent that to attempt to hold a non-scaling, non-decarburizing atmosphere in a gas furnace, it may best be accomplished by leading a jet of raw gas into the chamber independent of the burners. We have found that in this way atmospheres ranging all the way from scaling (oxidizing the iron) and non-decarburizing to non-scaling and carburizing, or any intermediate condition, such as non-scaling and neutral (as regards carburizing and decarburizing), may be secured at the will of the operator.

Appreciable quantities of sulphur in a furnace atmosphere are non-uniformly absorbed by the heated steel, and if this steel is later carburized, the sulphur-rich areas serve to concentrate the carbon in the form of hard raised spots. It is well known that oxygen in contact with steel at higher temperatures than these noted here causes the condition known as burning.

The chemical equations of the reactions that are responsible for the results shown in Conditions Numbers 1 to 5, inclusive, as well as the reactions and tables incorporated in the "Chemistry of Combustion," are purposely left out of the body of the paper.

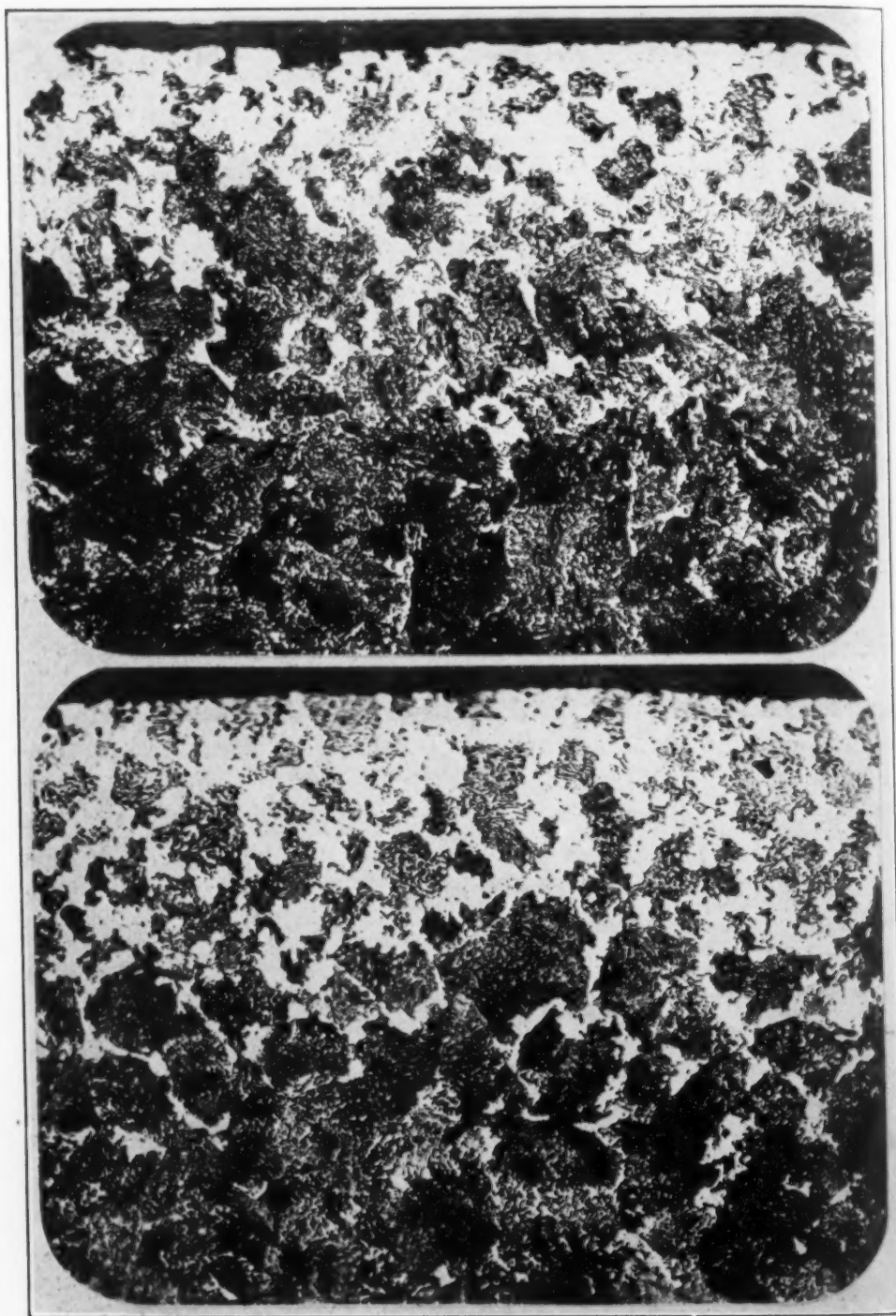


Fig. 6—Photomicrograph of Specimen Heated in CO_2 and CO (1 : 1) at 1500 Degrees Fahr. for 5 Hours and Slowly Cooled. $\times 170$. Fig. 7—Photomicrograph of Specimen Heated in CO_2 and CO (1 : 3) at 1500 Degrees Fahr. for 5 Hours and Slowly Cooled. $\times 170$.

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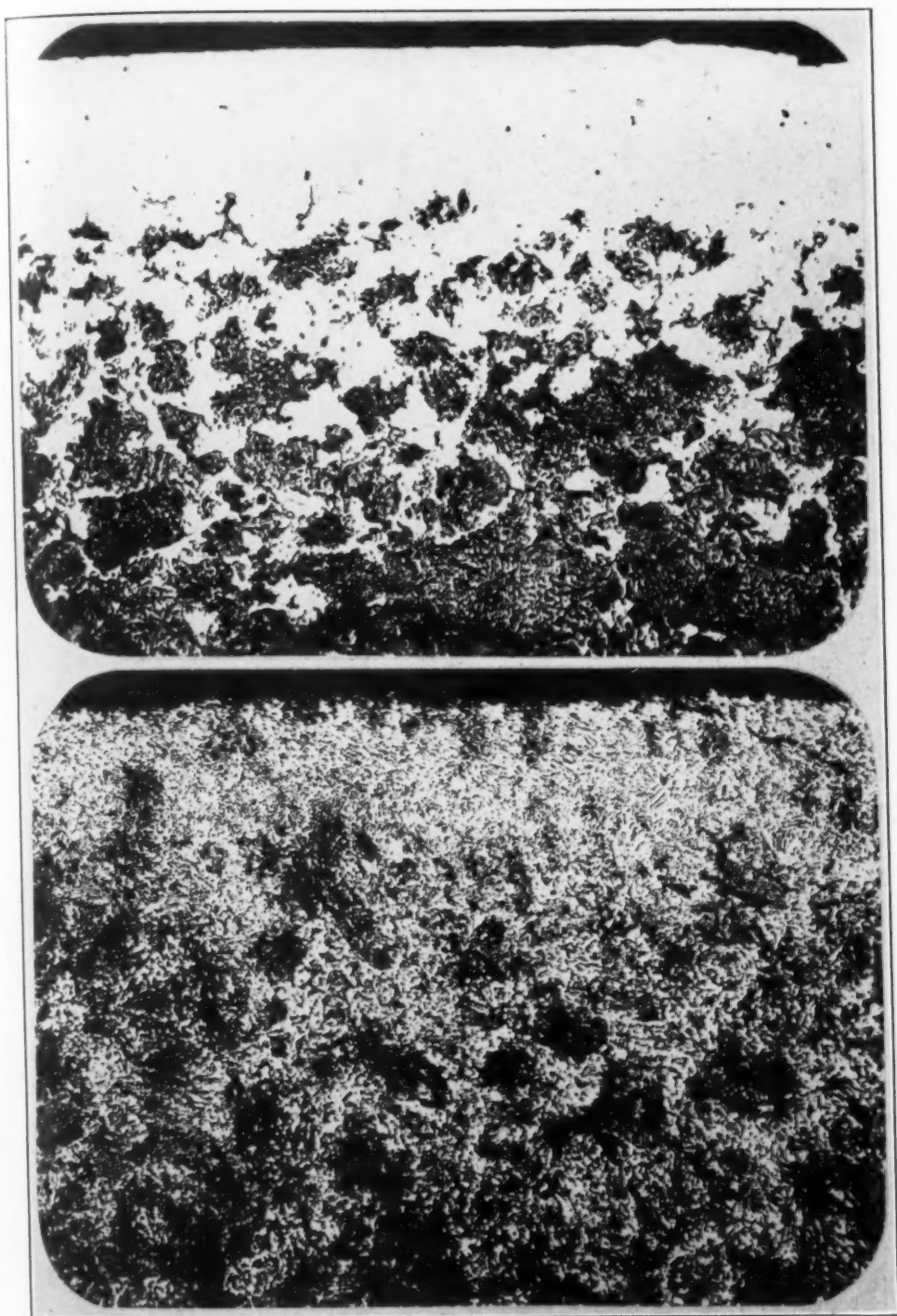


Fig. 8—Photomicrograph of Specimen Heated in CO_2 and CO (3 : 1) at 1500 Degrees Fahr. for 5 Hours and Slowly Cooled. $\times 170$. Fig. 9—Photomicrograph of Specimen Heated in CO and H_2 (1 : 1) at 1500 Degrees Fahr. for 5 Hours and Slowly Cooled. $\times 170$.

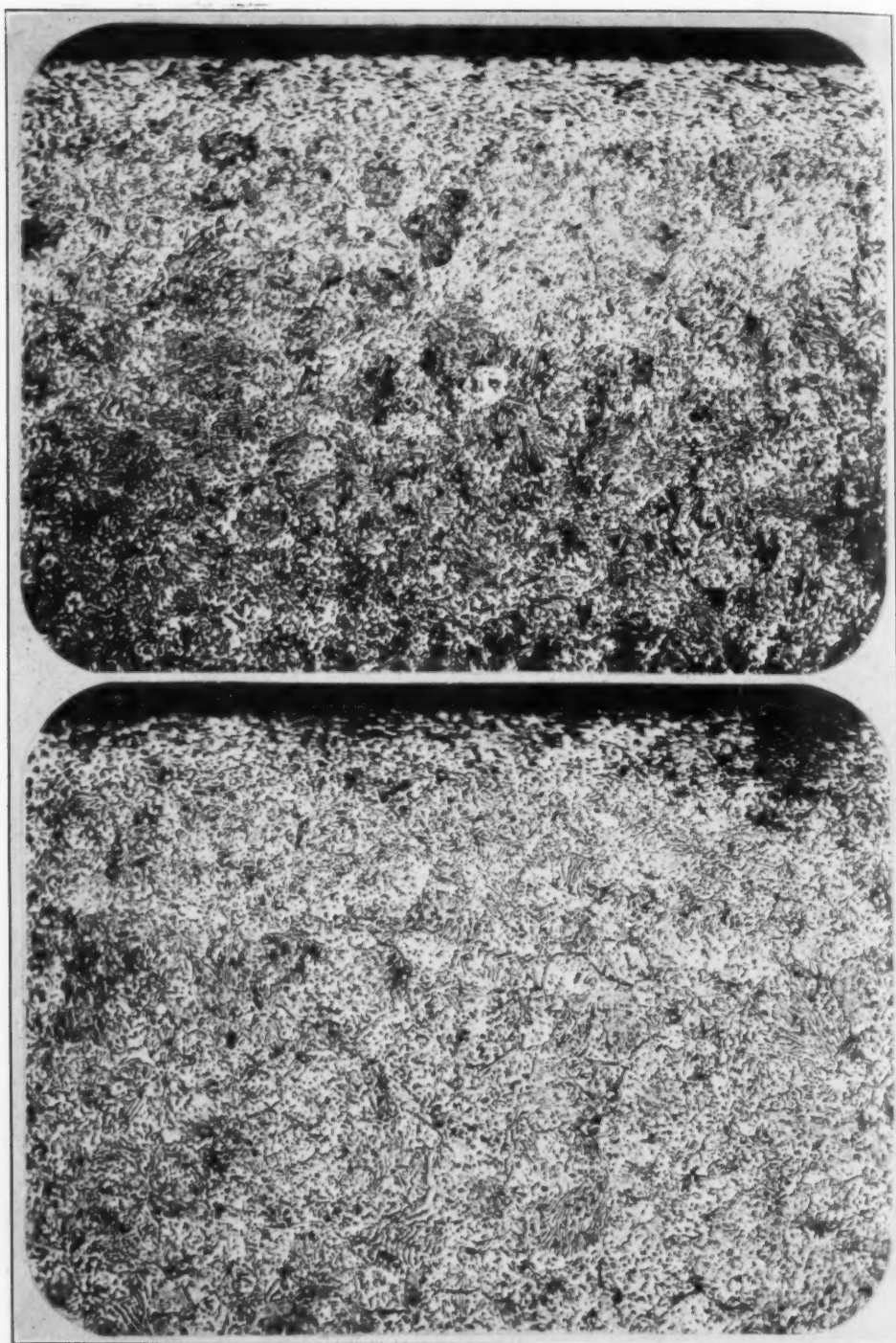


Fig. 10—Photomicrograph of Specimen Heated in CO_2 and H_2 (1 : 3) at 1500 Degrees Fahr. for 5 Hours and Slowly Cooled. $\times 170$. Fig. 11—Photomicrograph of Specimen Heated in CO and H_2 (3 : 1) at 1500 Degrees Fahr. for 5 Hours and Slowly Cooled. $\times 170$.

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In so doing it is our desire to clearly state the practical results of these fundamental experiments, so that the practical as well as the technical readers may benefit.

SUMMARY

This paper contains three practical and important points:

1. Sealing or oxidation with oxygen does not cause decarburization at these temperatures (1500 degrees Fahr.).
2. Carbon dioxide alone is not neutral and is both a decarburizer and oxidizer of iron and steel.
3. The intelligent use of raw gas, independent of that consumed through the burners, offers possibilities of extremely flexible conditions of furnace atmospheres, and is, therefore, a valuable adjunct to the heat treatment of steel.

ACKNOWLEDGMENT

The writer wishes to acknowledge his gratitude to the Vanadium Alloys Steel Company for the steel used in these experiments; to J. A. Comstock for the photomicrographs and other valuable aid; and to Dr. O. J. Wozasek for his excellent counsel as well as his "Chemistry of Combustion," which follows.

Editor's Note: The author has confined this paper to a study of the effect of the fundamental gases upon heated steel and has not wished to complicate matters by including a discussion of additions of other gases in varying proportions. He has, however, supplemented the work reported in this paper by a study of the effect of additions of other gases to the fundamental gases and has included a few of the results of interest to steel treaters in Figs. 6 to 11. In each case the top of the photomicrograph represents the outer surface of the piece. The captions accompanying the figures are self-explanatory.

APPENDIX

CHEMISTRY OF COMBUSTION

The chemical reactions for Conditions 1 to 5, inclusive, are:

Condition Number One (oxygen)

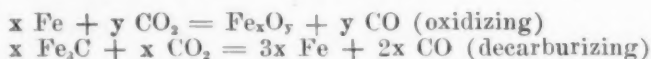


Table I

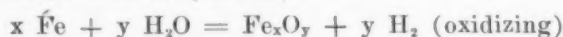
Data for the Combustion of One Cubic Foot of an Average City Gas at 32 Degrees Fahr. and a Pressure of 29.921 inches of Mercury at Different Conditions

	Combustion of dry air with dry gas		
	Theoretical Combustion	Combustion with 10% air excess	Combustion with 90% of the theoretical air
1 cu. ft. of gas requires cu. ft. of air both at standard conditions.	4.7416	5.21576	4.26744
Steam in pounds carried by the air.	.....	.....	.....
Steam carried by the gas.	.....	.....	.....
Steam carried by air and gas.	.....	.....	.....
Volume of the products of combustion in cu. ft. reduced to 32 degrees Fahr. and a pressure of 29.921 inch Hg.	0.614 cu. ft. CO ₂ 3.8916 cu. ft. N ₂ 0.986 cu. ft. H ₂ O	0.614 cu. ft. CO ₂ 4.26666 cu. ft. N ₂ 0.986 cu. ft. H ₂ O 0.0991 cu. ft. CO	0.4158 cu. ft. CO ₂ 3.51654 cu. ft. N ₂ 0.986 cu. ft. H ₂ O 0.1982 cu. ft. CO
Composition of the dry flue gas.	13.63% CO ₂ 86.37% N ₂	12.33% CO ₂ 1.99% O ₂ 85.68% N ₂	10.07% CO ₂ 4.80% CO 85.13% N ₂
Volume of the dry flue gas 32 degrees Fahr. and 29.921 inch Hg. pressure.	4.5056	4.97976	4.13054
Lb. of steam carried by the flue gas.	0.0498028	0.0498028	0.498028
Lb. per cu. ft. of flue gas of 32 degrees Fahr. and 29.921 inch Hg. pressure.	.011053	0.10001	0.012057
Approximative dew point of the flue gas.	137 degrees Fahr.	136 degrees Fahr.	130 degrees Fahr.

Condition Number Two (carbon dioxide)



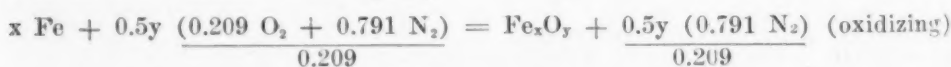
Condition Number Three (steam)



Condition Number Four (hydrogen)



Condition Number Five (air)



The ratio of iron to oxygen in each case is given by the letters x and y, as we feel that many types of iron oxide other than the commonly accepted ones are formed.

A. THEORETICAL FLUE GAS

The composition of an average city gas is as follows:

	Per Cent		Per Cent
CO ₂	3.3	H ₂	40.3
III.	5.5	CH ₄	20.9
O ₂	0.7	N ₂	14.1
CO	15.2		

The composition of the flue gas for the theoretical combustion of the above city gas can be calculated as shown below:

$$\begin{aligned}
 0.033 \text{ cu. ft. CO}_2 &= 0.033 \text{ cu. ft. CO}_2 \\
 0.055 \text{ cu. ft. C}_4\text{H}_8 + 0.3025 \text{ cu. ft. O}_2 &= 0.220 \text{ cu. ft. CO}_2 + 0.165 \text{ cu. ft. H}_2\text{O} \\
 0.007 \text{ cu. ft. O}_2 - 0.007 \text{ cu. ft. O}_2 &= 0 \\
 0.152 \text{ cu. ft. CO} + 0.0760 \text{ cu. ft. O}_2 &= 0.152 \text{ cu. ft. CO}_2 \\
 0.403 \text{ cu. ft. H}_2 + 0.2015 \text{ cu. ft. O}_2 &= 0.403 \text{ cu. ft. H}_2\text{O} \\
 0.209 \text{ cu. ft. CH}_4 + 0.4180 \text{ cu. ft. O}_2 &= 0.209 \text{ cu. ft. CO}_2 + 0.418 \text{ cu. ft. H}_2\text{O} \\
 0.141 \text{ cu. ft. N}_2 &= 0.141 \text{ cu. ft. N}_2
 \end{aligned}$$

Adding both sides of the above equations,

$$1.000 \text{ cu. ft. city gas} + 0.0010 \text{ cu. ft. O}_2 = 0.614 \text{ cu. ft. CO}_2 + 0.986 \text{ cu. ft. H}_2\text{O} + 0.141 \text{ cu. ft. N}_2$$

$$\text{Adding, } 3.7509 \text{ cu. ft. N}_2 = 3.7509 \text{ cu. ft. N}_2$$

$$1.000 \text{ cu. ft. city gas} + 4.7416 \text{ cu. ft. air} = 0.614 \text{ cu. ft. CO}_2 + 0.986 \text{ cu. ft. H}_2\text{O} + 3.9816 \text{ cu. ft. N}_2$$

The results of the combustion of 1 cu. ft. of dry city gas with dry air in the theoretical proportion are:

$$\begin{aligned}
 &0.614 \text{ cu. ft. CO}_2 \\
 &3.8916 \text{ cu. ft. N}_2 \\
 &0.986 \text{ cu. ft. steam} \\
 &\text{or } 5.4916 \text{ cu. ft. of wet flue gas} \\
 &\text{or } 4.5056 \text{ cu. ft. of dry flue gas}
 \end{aligned}$$

of the following composition:

$$\begin{aligned}
 &13.63 \text{ per cent CO}_2 \\
 &83.37 \text{ per cent N}_2
 \end{aligned}$$

Furthermore,

$$\begin{aligned}
 1 \text{ vol. CH}_4 &\text{ corresponds to } 2 \text{ vol. H}_2; 0.209 \text{ cu. ft. CH}_4 = 0.418 \text{ cu. ft. H}_2 \\
 1 \text{ vol. C}_4\text{H}_8 &\text{ corresponds to } 3 \text{ vol. H}_2; 0.055 \text{ cu. ft. C}_4\text{H}_8 = 0.165 \text{ cu. ft. H}_2 \\
 1 \text{ vol. H}_2 &\text{ corresponds to } 1 \text{ vol. H}_2; 0.403 \text{ cu. ft. H}_2 = 0.403 \text{ cu. ft. H}_2 \\
 &\text{or a total of } 0.986 \text{ cu. ft. H}_2
 \end{aligned}$$

Since 1 liter H₂ at 32 degrees Fahr. and 29.921 inch of mercury pressure = 0.08982 g,* and 1 cu. ft. = 28.316846 liter, then 1 cu. ft. H₂ = 28.3168 liters, or 2.543414976 g, or 0.005607236 pounds.

Then 0.986 cu. ft. H₂ = 0.005528734296 pound.

Furthermore,

1.008 pounds of H₂ combine with 8 pounds of O₂ to form 9.008 pounds of water, then 0.005528734296 pound of H₂ = 0.04980284

*Physikalisch chemische Tabellen, Landolt and Bernstein, 1923, page 270.

Table II

Data for the Combustion of One Cubic Foot of an Average City Gas at 32 Degrees Fahr. and a Pressure of 29.921 Inches of Mercury at Different Conditions

	Combustion of a gas saturated at 55 degrees Fahr. with air saturated at 70 degrees Fahr. to 80 per cent		
	Theoretical Combustion	Combustion with 10% air excess	Combustion with 90% of the theoretical air
1 cu. ft. of gas requires cu. ft. of air both at standard conditions.	4.7416	5.21576	4.26744
Steam in pounds carried by the air.	0.00478427	0.0052627	0.0043058
Steam carried by the gas.	0.00074361	0.00074361	0.00074361
Steam carried by air and gas.	0.00552788	0.00600631	0.00504941
Volume of the products of combustion in cu. ft. reduced to 32 degrees Fahr. and a pressure of 29.921 inch Hg.	0.614 cu. ft. CO ₂ 3.8916 cu. ft. N ₂ 0.986 cu. ft. H ₂ O	0.614 cu. ft. CO ₂ 4.26666 cu. ft. N ₂ 0.986 cu. ft. H ₂ O 0.0991 cu. ft. O ₂	0.4158 cu. ft. CO ₂ 3.51654 cu. ft. N ₂ 0.986 cu. ft. H ₂ O 0.982 cu. ft. CO
Composition of the dry flue gas.	13.63% CO ₂ 86.37% N ₂	12.33% CO ₂ 1.99% O ₂ 85.68% N ₂	10.07% CO ₂ 4.80% CO 85.13% N ₂
Volume of the dry flue gas 32 degrees Fahr. and 29.921 inch Hg. pressure.	4.5056	4.97976	4.13054
Pound of steam carried by the flue gas.	0.055330723	0.05580914	0.05485228
Pound per cu. ft. of flue gas of 32 degrees Fahr. and 29.921 inch Hg. pressure.	0.01228	0.011207	0.013279
Approximate dew point of the flue gas.	139 degrees Fahr.	137 degrees Fahr.	141 degree Fahr.

pound of water. This weight of water is carried by 4.5056 cu. ft. of dry flue gas. Therefore, 1 cu. ft. of flue gas at 32 degrees Fahr. and 29.921 inches of mercury pressure carries 0.011053 pound of water, corresponding to a gas saturated at about 137 degrees Fahr.**

B. COMBUSTION WITH AN AIR EXCESS OF 10 PER CENT

The equation of combustion changes as follows:

1 cu. ft. city gas 5.21576 cu. ft. air =
0.614 cu. ft. CO₂ + 0.986 cu. ft. H₂O + 4.26666 cu. ft. N₂ + 0.0991 cu. ft. O₂

The results of the combustion of 1 cu. ft. of dry city gas with dry air, both at 32 degrees Fahr. and 29.921 inch of mercury pressure are:

0.614 cu. ft. of CO₂
4.26666 cu. ft. of N₂
0.0991 cu. ft. of O₂

or total 4.97976 cu. ft. of dry flue gas (at standard condition),

**Using Steam Tables and Diagrams by L. S. Marks and H. N. Davis, Edition 1920.

carrying 0.049802839 pound of steam. The composition of the dry flue gas in per cent is:

12.33 per cent CO_2
1.99 per cent O_2
85.68 per cent N_2

a cu. ft. of this carries 0.010001 pound of steam corresponding to a saturation at of about 133 degrees Fahr.

C. COMBUSTION WITH 90 PER CENT OF THE THEORETICAL AIR

If we assume only 90 per cent of the theoretical air for the combustion of city gas it will proceed as follows:

0.033 cu. ft. $\text{CO}_2 = 0.033$ cu. ft. O_2
0.055 cu. ft. $\text{C}_4\text{H}_8 + 0.3025$ cu. ft. $\text{O}_2 = 0.220$ cu. ft. $\text{CO}_2 + 0.165$ cu. ft. H_2O
0.007 cu. ft. $\text{O}_2 - 0.0070$ cu. ft. $\text{O}_2 = 0$
0.152 cu. ft. $\text{CO} = 0.152$ cu. ft. CO
0.403 cu. ft. $\text{H}_2 + 0.2015$ cu. ft. $\text{O}_2 = + 0.403$ cu. ft. H_2O
0.209 cu. ft. $\text{CH}_4 + 0.3949$ cu. ft. $\text{O}_2 = 0.1628$ cu. ft. $\text{CO}_2 + 0.0462$ cu. ft. $\text{CO} + 0.418$ cu. ft. H_2O
0.141 cu. ft. $\text{N}_2 = + 0.141$ cu. ft. N_2
1 cu. ft. of city gas 0.8919 cu. ft. $\text{O}_2 = 0.4158$ cu. ft. $\text{CO}_2 + 0.1982$ cu. ft. $\text{CO} + 0.986$ cu. ft. $\text{H}_2\text{O} + 0.141$ cu. ft. N_2
3.37554 cu. ft. $\text{N}_2 = 3.37554$ cu. ft. N_2

1 cu. ft. of city gas + 4.26744 cu. ft. of air both at standard conditions (32 degrees Fahr. and 29.921 inch mercury) and dry give

	0.4158	cu. ft. of CO_2
	0.1982	cu. ft. of CO
	0.9860	cu. ft. of steam
	3.51654	cu. ft. of N_2
total	5.11654	cu. ft. of wet flue gas or
	4.13054	cu. ft. of dry gas carrying

0.04980284 pound of steam or per cu. ft. 0.0120572 pound corresponding to a saturation point of about 139 degrees Fahr. Flue gas composition:

10.07 per cent CO_2
4.80 per cent CO
85.13 per cent N_2

D. THEORETICAL COMBUSTION WITH A GAS SATURATED AT 55 DEGREES FAHR. AND AIR OF 70 DEGREES FAHR. OF A RELATIVE HUMIDITY OF 80 PER CENT

The steam content of a cubic foot of gas with a dew point of 55 degrees = 0.0007 pound per cubic foot. Its steam pressure is 0.4357 inches and the corresponding gas pressure is 29.4853 inches, when the barometric pressure is as high as 29.921 inches;

one cubic foot of gas at 32 degrees Fahr. and 29.921 inches mercury pressure when saturated at 55 degrees Fahr. increase to a volume of 1.0623 cubic feet and carries then 0.0007436 pound of steam.

One cubic foot of air of 70 degrees Fahr. with a relative humidity of 80 per cent carries 0.001148 pound of steam $\times 0.80 = 0.0009184$ pound.

Its dew point is about 63.6 degrees Fahr. The pressure of the steam is 0.5912 inches of mercury and the corresponding air pressure 29.3298 inch. One cubic foot of air at 32 degrees Fahr. and 29.921 inches mercury, when saturated at 70 degrees Fahr. to 80 per cent increase to 1.099 cu. ft. and carries totally 0.001009 pound of steam.

The volume of air required to oxidize one cubic foot of city gas is 4.7416 cubic feet of dry air, all at 32 degrees Fahr. and 29.921 inches of mercury pressure. The weight of water carried by both is

$$(4.7415 \times 0.001009 \text{ pound}) + 0.00074361 \text{ pound} = 0.0055278844 \text{ pound}$$

The total amount of steam is equal to $0.04980284 + 0.00552788385 = 0.0553607229$ pound for the theoretical combustion with a gas saturated at 55 degrees Fahr. and the air of 70 degrees Fahr. saturated to a relative humidity of 80 per cent.

The reduced flue gas volume for the theoretical combustion = 4.5056 cu. ft., therefore 1 cu. ft. corresponds to 0.01228 pound and the dew point of this mixture is about 139 degrees Fahr.

E. COMBUSTION WITH 10 PER CENT AIR EXCESS (GAS SATURATED AT 55 DEGREES FAHR. AND AIR SATURATED AT 70 DEGREES FAHR. TO 80 PER CENT)

The amount of dry air of 32 degrees Fahr. and 29.921 inch of mercury pressure necessary for this combustion (per cu. ft. of gas at the same conditions) are 5.21576 cu. ft. It carries then 5.21576×0.001009 pound of steam = 0.0052627 pound of steam. The gas brings in 0.0007436 pound, that are totally, 0.0060063 pound for 4.97976 cu. ft. of dry flue gas of 32 degrees Fahr. and 29.921 inch of mercury pressure or per cu. ft. 0.0012061 pound + 0.010001 pound from the combustion = 0.011207 pound per cu. ft. of flue gas. The dew point of this mixture is a little lower than 137 degrees Fahr.

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F. COMBUSTION WITH 90 PER CENT OF THE THEORETICAL AIR
(GAS SATURATED AT 55 DEGREES FAHR. AND AIR SATURATED AT
70 DEGREES FAHR. TO 80 PER CENT)

The volume of air required is 4.26744 cu. ft. at 32 degrees Fahr. and 29.921 inches of mercury pressure. This air carries $4.26744 \times 0.001009 = 0.004305847$ pound of steam. The gas is loaded with 0.0007436 pound and the combustion delivers 0.0498028 pound or 0.05485228 pound total, i. e., per ft. of dry flue gas of 32 degrees Fahr. and 29.921 inches mercury pressure 0.013279 pound and the dew point of this gas is less than 141 degrees Fahr. (dry flue gas vol. 4.13054 cu. ft.).

DISCUSSION

CHAIRMAN TRINKS: I had always thought that sulphur is not absorbed until the steel becomes plastic enough to be sticky, but according to Mr. Guthrie, it is apparently absorbed at a lower temperature. It might not do any harm to have the composition of the steel added, Mr. Guthrie. It might make a difference whether there is chromium or copper or still other constituents in the steel.

R. G. GUTHRIE: This particular steel had no chromium or copper in it. It was a straight carbon steel, there are no alloys present in the material. The analysis of the steel used is as follows: carbon—0.90 per cent; manganese—0.20 per cent; phosphorus and sulphur—0.03 per cent; silicon—0.25 per cent. I would like to say a word regarding that sulphur. At what stage of the fabrication of that material that caused this trouble with the absorption of the sulphur, the sulphur got into it, we are not prepared to state. In our experimental furnaces, however, we have difficulty with sulphur at very much lower temperatures than the sticky state, and Dr. Wozasek probably will recall how low he went before he had no trouble. You got sulphur absorption at quite low temperatures, did you not?

DR. O. J. WOZASEK: Yes, about 1600 degrees Fahr.

R. G. GUTHRIE: And that corresponds with the practical trouble we have had in the plant from material that was forged and then later carburized and gave that same trouble—blistering. I am not prepared to say as to how low that temperature might go before that would cease nor how much is absorbed at even 1600 degrees Fahr.

N. ELBOGEN: Mr. Chairman, at this morning's session Mr. Davis made mention of the fact that humidity had considerable effect, in some experiments they made, on the results obtained in their heat treating operations, and I just wondered if someone here could tell us about how humidity could be counteracted in cases of that sort.

R. G. GUTHRIE: We have had a great deal of trouble with humidity in carburization. In fact, I think I can safely state that we have never been able to carburize successfully and constantly with Chicago city gas without de-

humidifying it. For the small load that we use in carburizing in furnaces up to 1500 pounds capacity we use calcium chloride tubes, that is, an ordinary 8-inch pipe 6 or 8 feet long, two of them in a series, and pass the gas through.

I will also say that we do not know, but would like to know the effect of humidity on combustion. We suspect possibly that it has some effect, but we cannot prove it so far. This paper is merely one of the stepping stones in that direction. But in carburization, either in the compound or in the gas, we have had great difficulty with variable moisture content.

A situation arose which, I think, is characteristic. A compound was being used in a rotating retort-type furnace and the difficulty encountered was a sticking together of the pieces. This caused an imperfect carburization of those pieces. Nothing was done to eradicate or eliminate that difficulty except the use of dry compound. The compound was dried and put in the furnace before it had an opportunity to absorb any appreciable amount of moisture and the difficulty disappeared. That is not one case alone, but one of many instances that have happened along that line.

M. H. MAWHINNEY: Are there any conclusions on the effect of CO, on the carbon content, of the steel in the carburization process?

R. G. GUTHRIE: The effect of CO has been studied a good deal more thoroughly by Mr. Sykes than it has by us in that connection. We have some information on carburization where CO is one of the gases, but we have no definite conclusions formed on that subject at all. In fact, I might say in my own defense that we have no definite conclusions on any of these, they are perfectly open.

H. A. CLARK: May I ask Mr. Guthrie whether or not he finds that Chicago city gas if dehydrated, that is, if passed through this calcium chloride, is suitable as carburizing agent?

R. G. GUTHRIE: We have one company which has been operating on an average of a little better than nine hours a day on heavy gears, as well as small parts, continuously, six days a week, for a year and three months without any trouble, and have been able thus far to predict the depth of case as well as the concentration within practical limits on their parts during all that time. Previous to that time, using the same gas, were not able to get consistent results for any reasonable period. They would go along, for instance, getting a sixteenth of an inch depth on certain of their parts in six to seven hours and all at once, without any apparent reason whatsoever, that same depth case on the same parts and under identical operating conditions would take them 18 or 20 hours. They have never had that difficulty since the dehydration has been in effect.

Another concern that has lately gone under that process, that is, four months ago, who had a similar situation prior to that time and gave up the carburization with city gas, and they now have a record of three months continuous carburization, about 12 hours a day, on two alloy steels, one low carbon, low chromium, and one nickel-molybdenum and they have had no trouble at all and they have run continuously during that time without any difficulty.

H. A. CLARK: The fragmentary information available upon the use of city gas for carburizing has given me the general impression that the thing

that caused city gas to fail as a carburizing agent was the hydrogen content. For that reason we have been rather inclined to welcome the incoming of those hydrocarbons that are distilled from natural gas, and which are possible agents for carburizing by a gas.

R. G. GUTHRIE: Mr. Manier of Syracuse will be able shortly to give you some additional information on that subject that we will welcome, whether it be good or bad, because it will either be a confirmation of the information I have just given or it will refute that information. I can say and prove that up to date in the plants of our customers who are using this process, we are having excellent success. Now, I do not know what success is being had with that in other gas plants, that is, other towns that are using manufactured gas, but I think I am safe in saying that Mr. Manier will be able to give you that information very shortly, as one of their large customers is now trying that same process.

R. L. MANIER: We have been doing considerable gas carburizing in the Syracuse territory and found that in one particular location we were having difficulty. At that time we went out and consulted with Mr. Guthrie as to their findings and when we learned that relative humidity of the gas was the paramount factor, we began to see the cause of our trouble. We found that the jobs which were perfectly satisfactory were those far distant from our holder, where the relative humidity would tend to remain quite constant, while the jobs that were giving trouble were those within a block of our main gas holder, where the gas, coming in contact with water, varied decidedly with different temperatures during the season.

In that particular job a series of tests had been carried through with Carbofax gas with very satisfactory performance as regards uniformity of penetration, the straight carbon line, and very satisfactory results all through, both in the rotating and the non-rotating type of equipment, and now we are going, after having obtained the data on the Carbofax, to see what city gas will do. I do not at this time wish to state what our expectations are until the results finally come through. City gas would, without a doubt, be cheaper. The volume used is such that the gas companies are not fighting for it. It is just a matter that if our customers come to us, we will try to do what we can for them. The indications are that Mr. Guthrie's experience will be repeated at Syracuse. In other words, if we dehydrate the gas and properly prepare the material, gas carburizing will prove very satisfactory for the particular work at hand.

CHAIRMAN TRINKS: As I understand it, you have in that furnace no combustion whatsoever.

R. L. MANIER: Within the retort there is no combustion. In the case of the city gas, just the raw gas is put in there. In the case of the Carbofax tests that have been conducted, the gas has been sent in with a certain amount of air through a machine which automatically holds the certain predetermined air-gas ratio that is recommended by the Carbofax people. That is thoroughly protected by explosion devices, so there is a minimum of hazard.

CHAIRMAN TRINKS: In physical chemistry I have always learned that you cannot have combustion of carbon unless there is water vapor present. That

is to say, that carbon will not form carbon monoxide and later on, carbon dioxide, unless there is water vapor present, but that an extremely small quantity of water vapor is sufficient to start a catalytic action by way of the water gas reaction, but that you can never have combustion of carbon in a perfectly dry atmosphere.

R. L. MANIER: With the city gas, water is admitted as a preparatory measure, in the early stages, and forms a slight oxide which acts as a catalyst with the gas, apparently, to bring about a condition where the carbon is readily absorbed. That has not been done, however, in the case of Carbofax.

CHAIRMAN TRINKS: I think the author of the paper will have something to say about that. It is not the hydrogen alone that does it, it is water vapor in the air.

R. G. GUTHRIE: I wanted to explain that the addition of water vapor at the beginning of the run amounts to only ten drops per minute for three minutes in a gas flow of 75 cubic feet an hour at 15 pounds per square inch. We have found by trial in the laboratory furnaces, as well as the large furnaces, that water amounting to ten drops a minute was correct,—we did not work it out in the laboratory on the basis of drops per minute, but we merely gave that to the plants so it would be possible for them to use an ordinary engine lubricator. The time that the calcium chloride needs to be dried is directly dependent upon the amount of moisture in the gas. As Mr. Manier brought out, their plant was near the holder. We have one plant situated in a part of town where it is necessary that they dry that calcium cartridge once a week for satisfactory results, while in another plant which is in a new district, with new piping, irrespective of its location in relation to the holder, the piping is tight and it is on a higher pressure line and it is only necessary there to dry this same size cartridge, carrying the same amount of gas through it, once every three months.

H. T. MORTON: In talking to Mr. Manier and the metallurgist of the company to which he refers, they spoke about drying the gas and adding moisture to it during the first few minutes of the run. I would like to ask as to the amount of moisture added to a particular size furnace. I am wondering if you have found limits as to the composition of city gas for carburizing purposes. By that I mean what hydrocarbons and in what percentage are they necessary for good results? Do you know of anybody who has worked out these results?

R. G. GUTHRIE: In answer to that, I should say that our gas contains a proportion of CO_2 to illuminants of about $1\frac{1}{2}$ to 2 per cent CO_2 and 3 to 5 per cent of illuminants. We have a practical rule in our own laboratory that we go by that may answer that question, that any gas that we can produce within the requirements of the Illinois Public Utilities Commission will be taken care of by this ten drops of water per minute for three minutes in that type and size of furnace providing we use thoroughly dried gas for the remainder of the carburizing time. We have found that the water practically inhibits the deposition of soot. What else it does or how many other things it may do, we are not prepared to state because we do not know; but we have set up two 1500-pound furnaces with a T-connection between them from the

same line, to the same risers, and run them under identical conditions, using the ten drops of water in one and omitting the ten drops of water in the other. The carburizing time and the concentration of case are not so far different that it is materially important, that is, they are about an hour to two hours apart in favor of the furnace that uses the water vapor, but the retort in the case of the furnace not using the water vapor was about half full of soot and the retort in the case of the furnace using the water vapor had less than I could hold in both my hands. The furnaces were operated under identical conditions as near as it was possible for us to run them.

CHAIRMAN TRINKS: May I ask whether it makes any difference whether the city gas is water gas or coal gas?

R. G. GUTHRIE: Well, our gas is a mixed coal gas and water gas, although we have made runs in the laboratory using a carbureted blue water gas with the same results. It contains about eight per cent illuminants, the percentage of CO was, roughly, in each instance, about half that of the illuminant content. How important that is, I do not know. Possibly Dr. Wozasek does. We have not run a carbureted blue water gas in the plants because our send-out is a mixed gas.

DR. O. J. WOZASEK: It makes no difference which kind of gas you are using. Assuming that you have this very small amount of moisture, it is all right.

CHAIRMAN TRINKS: But you must have illuminants in the gas? A straight blue water gas would not work, would it?

R. G. GUTHRIE: A straight blue water gas works with carburizing compound.

CHAIRMAN TRINKS: But not with a straight blue gas?

R. G. GUTHRIE: We do not know. We do know that down to one and one-half per cent illuminants, it still works, because apparently at 75 cubic feet an hour in a 1500-pound furnace, $1\frac{1}{2}$ per cent of illuminants is enough. In other words, the process is extremely inefficient as regards available carbon and that is why it is so cheap.

I might say, though, and this may answer your question, that we have found we actually get a decreased case, that is, not a decreased case but an increased time if we use 75 cubic feet an hour in the rotary furnaces on 500 to 700 pounds of steel, small parts, and that was our practice in using the gas dehumidified. As it comes from the main and at 15 pounds to the square inch, we used to have to use 75 cubic feet per hour to get the case. We found that the new process failed the first two or three times we tried it and everything else we tried failed until we cut down the amount of gas to 25 to 35 cubic feet per hour and found that it worked far better than the 75 cubic feet did in the dry gas.

May I just have the time to give you comparative figures on that? Comparative figures, using the parts made of 1020 S. A. E., were 0.036 inch case in three hours at 1750 degrees Fahr., 75 cubic feet of gas per hour, and when the dry gas was used and the water vapor added at the beginning of the run such as has been explained, the figures were 0.043 inch case at 1700 degrees Fahr. for two and one-half hours, and 0.056 inch case at 1750 degrees Fahr.

for three hours, which corresponded in time and temperature exactly to our former practice; and if those two are compared, you have, for the same cost and the same depreciation on the furnace, etc., 0.056 inch case in the case of the dry gas as against 0.036 inch case in the case of that gas as it comes from the mains.

CHAIRMAN TRINKS: Mr. Guthrie either has a very good memory or he has learned his lesson extremely well.

R. W. WOODWARD: May I ask Mr. Guthrie what he is considering as the depth of case there? In other words, when he says 0.036 inch case, does he mean all of the carbon penetration?

R. G. GUTHRIE: We have 194 plants, of which I think 94 are carburizing, and no two of those 94 measure the case alike. In this particular instance, they take the depth of the case, their laboratory measures it under a micrometer, and they take it at a median drawn as near as they can between the core and the case, where the case actually leaves off and the carbon drops to the concentration of the core. We have other plants that take it only where it is at least the eutectoid and no hypereutectoid zone in there, but that is rather difficult.

Now, on straight chromium, and nickel-molybdenum steels we do not use that same process, and that may further contribute some thoughts, because there is one manufacturer who demands that the same depth of case be put upon two articles, both about the same maximum cross section and the same depth of case, namely, 1/16 of an inch, the way he measures it, and neither to have the hypereutectoid zone in the outer edges when finished.

It is necessary, we find, with the chromium steel, that the gas be humidified with a predetermined amount of moisture throughout the run if the hypoeutectoid case is to be avoided. On the other hand, the nickel-molybdenum steel will stand the same relative carburizing cycle, namely, ten drops of water a minute and then dry gas, for the same depth. However, if we carburize them the same, we immediately get the impression, which we believe ourselves, at least, that the depth of case is not a factor of the concentration, or vice versa, that is, it is entirely possible to get that same depth of case with several concentrations by the manipulation of that particular type of gas, both as to rate of flow and moisture, and this morning in that discussion on that paper on the decarburization of steel in carburizing atmospheres, the statement was made that a carburizing gas was both at one and the same time, a decarburizer as well as a carburizer. In other words, gas such as we use for carburization, if it is put in a closed retort with the steel and not allowed to flow over the material, but to stagnate, will actually decarburize a hypereutectoid piece. That same gas, if given a rate of flow over the work, will carburize. That fact is apparently closely related with the fact that these two types of steel do not react the same to carburization.

DEPTH AND CHARACTER OF CASE INDUCED BY MIXTURES OF FERRO-ALLOYS WITH CARBURIZING COMPOUNDS

BY E. G. MAHIN AND R. C. SPENCER

Abstract

It has been known that the various elements occurring in steel affect the rate of carbon absorption and carbon migration during surface carburization, and that iron or steel may be "cemented" with various elements besides carbon, by heating pieces packed in compounds of these elements to temperatures below those of fusion. The experiments described in this paper show that if silicon absorption is confined to surface layers of iron or steel, carbon absorption during case carburization may be retarded without materially affecting the rate of inward migration of the carbon after it has been absorbed. By utilizing this principle it has been found possible to produce a deep case without a zone of free cementite, by using an ordinary carburizer in conjunction with ferrosilicon and by employing higher carburizing temperatures, thus shortening the time required for completing the case carburization.

DURING the course of an investigation concerning the nature of the effects produced by various nonmetallic inclusions upon carbon distribution in steel, attention was drawn toward an influence upon case carburization, shown by various ferro-alloys when these alloys were mixed with ordinary solid carburizing compounds. A brief preliminary account of the latter experiments was published.¹ This work was later continued and the results were embodied in a master's thesis.* The present account is to deal with a more detailed study of the action of only one of these ferro-alloys

¹Mahin, Spencer and Hayner, *Proceedings, Ind. Acad. Sci.*, Vol. 34, 1925, page 177.

*R. C. Spencer.

A paper presented before the tenth annual convention of the society, held in Philadelphia, October 8 to 12, 1928. Of the authors, who are members of the society, E. G. Mahin is Professor of Metallurgy at Notre Dame University, Notre Dame, Ind., and R. C. Spencer is metallurgist with the Caterpillar Tractor Company of Peoria, Ill. Manuscript received June 29, 1928.

—ferro-silicon—when used in admixture with a commercial carburizing material.

HISTORICAL REVIEW

Elements Alloyed With Steel—As early as 1870 Margueritte had concluded, from calculations based upon cementation with carbon monoxide, that most of the common elements in steel exerted some influence upon carburization, although this effect was usually small.

Sauveur states² that Guillet's work indicates that elements which form double carbides accelerate carbon absorption, while those which remain in solid solution in ferrite have the opposite effect. The latter class would include, among others, nickel, silicon and aluminum. Merten substantiated this general rule.³ Tammann found⁴ that molybdenum, tungsten, nickel, manganese and cobalt increased diffusion up to a certain maximum, after which their effect diminished. His work indicated that antimony and vanadium slowed penetration, while aluminum showed no important effect.

Spalding⁵ compared the rate of carbon migration in commercial steels. He found that unduly high percentages of phosphorus and sulphur retard carbon penetration, while chromium has the opposite effect. Shepherd found⁶ that chromium-vanadium steels carburize more readily than carbon steels, regardless of the nature of the carburizing compound. In the opinion of Ehn⁷ the presence of dissolved oxides produces "abnormality" during carburization.

Elements Absorbed by Cementation—Many different substances have been added to carburizing materials in an effort to increase the activity of the mixture. Even at present, many secret mixtures are being exploited, most of which resolve themselves into the ordinarily used carbon and nitrogen compounds, with various carbonates as energizers and with diluents of questionable value.

²"The Metallography and Heat Treatment of Iron and Steel," 3rd edition, p. 294.

³TRANSACTIONS, American Society for Steel Treating, Vol. 2, 1922, p. 950.

⁴*Stahl und Eisen*, Vol. 42, 1922, page 654.

⁵TRANSACTIONS, American Society for Steel Treating, Vol. 2, 1922, p. 950.

⁶TRANSACTIONS, American Society for Steel Treating, Vol. 6, 1924, p. 606.

⁷*Iron Age*, Vol. 109, 1922, p. 1807.

Metallic coatings are produced upon steel or iron by such processes as "sherardizing," "calorizing" and "chromizing," protective coatings of zinc, aluminum and chromium, respectively, being produced by heating the article in contact with metallic powders.

Laissus⁸ embedded samples of steel in powdered ferrochromium and heated to carburizing temperatures. He obtained a thin coating of high chromium steel, which was very resistant to corrosion.

Miyaguchi⁹ obtained a very hard and tough layer on an iron or steel by a process in which the specimens were heated in contact with carbon powder and boron oxide. Other attempts have been made to utilize boron in case carburizing but apparently no practical applications have been made.¹⁰

Laissus has shown¹¹ that by cementation with the appropriate ferro-alloy at 1472 to 2192 degrees Fahr. (800 to 1200 degrees Cent.) in the presence of ammonium chloride, coatings of high tungsten, molybdenum or tantalum content may be produced on iron or copper alloys.

Moissan¹² studied the cementation of iron with silicon, chromium and silver. He found that when cylinders of soft iron were packed in crystals of silicon and heated to the temperature of a "good forge," they were silicized even to the axes, there being a uniform silicon content of two per cent.

Stead,¹³ on the other hand, heated carbon steels in crystals of pure silicon for two hours at 2055 to 2143 degrees Fahr. (1125 to 1175 degrees Cent.), but obtained no silicon penetration. A similar experiment, heating for two and one half hours at 2372 to 2462 degrees Fahr. (1300 to 1350 degrees Cent.), resulted in a uniform fusion containing 13.54 per cent of silicon. He concluded that Moissan's results were due to partial fusion and that no silicon had entered the metal by solid solution.

Thomson¹⁴ heated iron bars, packed in powdered silicon. He

⁸*Comptes Rendus*, Vol. 180, 1925, p. 2040.

⁹British patent 193,917, Nov. 3, 1921.

¹⁰See Chivenskii: *Journal, Iron and Steel Institute*, Vol. 95, 1917, p. 185; Campbell and Fav, *Journal of Industrial and Engineering Chemistry*, Vol. 16, 1924, p. 719; Feszczenko-Czopwsk: *Revue de Métallurgie* (extracts), Vol. 23, 1926, p. 267.

¹¹*Comptes Rendus*, Vol. 182, 1926, p. 1154.

¹²*Comptes Rendus*, Vol. 121, 1895, p. 621.

¹³*Journal, Iron and Steel Institute*, Vol. 67, 1903, p. 271.

¹⁴Research Laboratory of Applied Chemistry, Report of May 26, 1909.

obtained no penetration of silicon at temperatures below 2012 degrees Fahr. (1100 degrees Cent.), but some superficial combination of silicon and iron between 2012 and 2462 degrees Fahr. (1100 and 1350 degrees Cent.). At higher temperatures fusion occurred. Below the temperature of fusion the depth of silicon penetration was proportional to the time of cementation, a two-hour treatment giving a case of silicon about 0.02 inch in depth. The case was discontinuous and it could not be improved by annealing for two hours at 2282 degrees Fahr. (1250 degrees Cent.).

Lebeav¹⁵ obtained a reaction between reduced iron and silicon at 1742 degrees Fahr. (950 degrees Cent.). He was led to believe that silicon, like carbon, would penetrate iron at temperatures below fusion.

Haslam and Carlsmith¹⁶ found that when iron was heated in contact with ferrosilicon there was some silicon cementation. Penetration began at about 1472 degrees Fahr. (800 degrees Cent.) and increased in velocity up to about 2192 degrees Fahr. (1200 degrees Cent.), where fusion generally occurred. They accounted for this cementation upon the basis of the comparatively high vapor tension of silicon, and upon the fact that the reaction between iron and silicon is exothermic.

Vawter¹⁷ studied a process of coating iron with silicon, in order to provide protection against corrosion. He used silicon hydride at temperatures between 752 and 1112 degrees Fahr. (400 and 600 degrees Cent.), but the coating which was formed appeared to be superficial and it easily flaked off. He concluded that no practical use could be expected from this method.

Fry¹⁸ obtained silicon penetration of about 0.6 millimeter, after heating soft steel in ferrosilicon for 110 hours at 2102 degrees Fahr. (1150 degrees Cent.).

Guillet¹⁹ heated low carbon steel in a reducing atmosphere in 75 to 80-per cent ferrosilicon, obtaining a penetration of 0.5 to 2.5 millimeters in three to four hours at 2012 to 2192 degrees Fahr. (1100 to 1200 degrees Cent.) when ammonium chloride was

¹⁵*Bulletin, Société Chimique de France*, Vol. 27, 1920, p. 3.

¹⁶*Journal, Industrial and Engineering Chemistry*, Vol. 16, 1924, p. 1110.

¹⁷*Journal, Industrial and Engineering Chemistry*, Vol. 9, 1917, p. 580.

¹⁸*Stahl und Eisen*, Vol. 43, 1923, p. 1041.

¹⁹*Comptes Rendus*, Vol. 182, 1926, p. 1588.

mixed with the ferrosilicon, but not otherwise. Guillet thus obtained an acid-resisting surface containing about 15 per cent of silicon.

THE PRESENT PROBLEM

The above review has indicated that various investigators have found it to be possible to "cement" the surface of iron or steel with any one of a number of elements which are capable of dissolving in iron at temperatures below its fusing point, although there is considerable disagreement as to the conditions under which such penetration of the foreign element may take place. No important practical application of such a process has as yet been seen, except the protection of the surface of the metal from corrosion by electrolytes, and such protection may, in many cases, be obtained more readily by electroplating.

It has been proved also that when other elements are already dissolved uniformly in iron or a low carbon steel, the rate of carbon cementation and the character of the case produced by such carburization is affected. However, the utilization of these effects is limited by the fact that such added elements must usually be held within rather narrow limits established by commercial practice, in order that the carburized and hardened piece may possess the required physical properties.

It seemed to be worth while to determine whether the depth of carbon penetration during case carburization, and the character of the case so produced, might not be affected in a useful manner by altering the per cent of a third element in the outer layers of the case alone, leaving the core of the finished piece in substantially the same condition as would be obtained by carburizing by the usual method.

Character of Case—The character of the case desired in commercial applications of course varies according to the special service requirements of the case carburized article. Since the primary object of all surface carburization is to produce a hard wearing surface, without destroying the ductility of the body, it may be assumed that the usual aim is the production of a case of the necessary depth and high carbon exterior layers, without excessive brittleness of the surface of the heat treated piece.

Depth of Case—With steel of a given composition, the prin-

principal factors affecting the rate of carbon absorption at the surface are temperature and nature of carburizing compound. The rate of absorption of course increases with rise in temperature. And the character of "slow" and "sudden" carburizers has been discussed so thoroughly by various authors that there seems little point to repeating this discussion here.

The rate of inward migration of the absorbed carbon depends upon temperature and upon concentration gradient, although the latter factor appears to be of less importance than is that of temperature. The total depth of case increases with time of heating, rise in temperature and concentration gradient but, here again, time and temperature appear to be the more important factors.

Properties of Case—Having established, as a result of commercial practice, the necessary depth of case for a given service, there remains the question as to the carbon distribution within this case. The outer surface should have as high carbon content as possible without imparting undue brittleness after thermal treatment, in order to confer upon the surface the maximum practicable resistance to wear or abrasion. Where the piece is to be subjected to no great stresses, higher carbon content is permissible than otherwise and hypereutectoid outer zones may carry as much as 1.8 per cent of carbon.

For a great many other uses the outer case should not carry more than about 0.9 per cent of carbon, so that a microscopic examination of a cross section would indicate an eutectoid outer zone, passing into the usual hypoeutectoid zone with carbon decreasing toward the inner line of the case.

Case Failures—Aside from the occasional failure of a too soft case, due to insufficient or uneven carburization or to improper thermal treatment, cracking or exfoliation of the case may sometimes occur, during hardening treatments or after the piece has been placed in service. It is axiomatic that as the carbon content rises, increasing care and skill must be exercised during the thermal treatment of the case carburized piece. Quenching stresses may be generated, so severe as to cause cracking, either during the process of heat treatment or after service stresses are added to these.

Exfoliation of the case is not an uncommon type of failure. This also may occur during quenching or when the piece is in

service and is evidenced by the case tearing away from the body in shells, the thickness of which corresponds with the depth of one of the three zones of the case.

It has been shown by Giolitti that exfoliation of a case is due principally to uneven carbon gradients. While carbon absorption and inward migration are in process (i.e., while the steel is in the austenitic temperature range) the carbon distribution curve is a regular one, as might be supposed. But if the piece has been given a hypereutectoid outer case and if it is allowed to cool slowly in the box, as is so frequently done, "liquation" takes place. This is due to the fact that cementite, at the outer surface, and ferrite, toward the core, are rejected as separate phases at higher temperatures during cooling and these phases "seed out" from the austenite lying between. This results in the formation of a broad eutectoid band lying in an intermediate position, the slope of the carbon curve changing suddenly at both sides of this.

It should be noted that this interpretation by Giolitti has been disputed.²⁰ Whether or not such a phenomenon as "liquation" occurs during slow cooling, this or some similar action must be the cause of the fact that a slowly cooled case carburized piece shows a band, rather than a line, of pearlite.

After the thermal treatment of such a piece has been completed there exists, as a result of the discontinuity in carbon distribution, a sudden change in hardness and tensile strength at the junctions of the three zones of the case. This is more pronounced at the junction of hypereutectoid and eutectoid zones and it is in this region that rupture usually occurs, because of the better support and higher ductility that exist where the eutectoid merges into the hypoeutectoid zone.

Two curves are here adapted (Figs. 1 and 2) from Giolitti's book, "Cementation of Iron and Steel." These illustrate the approximate carbon distribution, first while the piece is still hot, at the end of the carburizing period, and, second, after slow cooling in the box.

Quenching from the box fixes the regular carbon distribution but this is not always practicable. Also the regularity is somewhat destroyed by subsequent heating for grain refinement.

Because of these and other limitations it is often desired to

²⁰Bramley and Jinkings: *Journal*, Iron and Steel Institute, Carnegie Scholarship Memoirs, Vol. 15, 1926, p. 17. Bramley and Beebe: *Ibid.*, Vol. 15, 1926, pp. 71 and 127.

obtain a case whose maximum carbon content in the outer layer will give eutectoid or, at most, only slightly hypereutectoid composition. In order to accomplish this result it becomes necessary

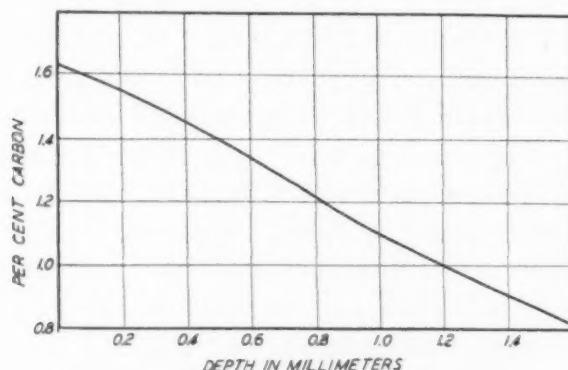


Fig. 1—Diagram Showing Carbon Distribution in a Steel, Carburized in Ethylene at 1832 Degrees Fahr. (1000 Degrees Cent.) and Quenched from the Same Temperature. (From Giolitti: "Cementation of Iron and Steel.")

to reduce the rate of carbon absorption, so that carbon migration may more nearly keep pace with it without building up excessive carbon content at the surface. In order to do this one may resort

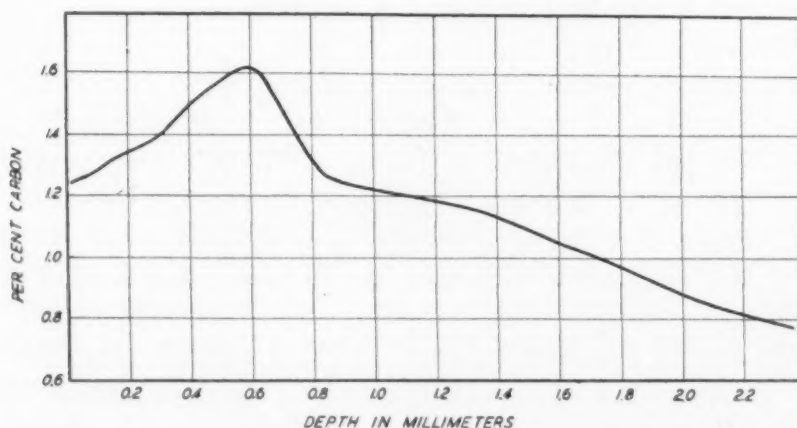


Fig. 2—Diagram Showing Carbon Distribution in a Steel, Carburized in Ethylene at 1832 Degrees Fahr. (1000 Degrees Cent.), Slowly Cooled to 1382 Degrees Fahr. (750 Degrees Cent.), then Quenched. (From Giolitti: "Cementation of Iron and Steel.")

to the use of "slow" carburizers or to lower temperature ranges for carburization. In either event, the time necessary for the production of the required depth of case is prolonged and this, of course, slows production unless additional equipment is employed.

It has already been stated that a number of investigators have

established the facts that (a) various metals and non-metals may be absorbed by iron or steel when the latter is embedded in their compounds and heated to temperatures below fusion, and that (b) most of these elements, when present in steel, either accelerate or retard the absorption and migration of carbon during the progress of the carburizing process.

Silicon exerts an influence in the direction of retarding carburization. If the silicon content could be increased only at the outer skin of the piece, the absorption rate for carbon might be diminished, without at the same time affecting the migration rate of carbon after the latter had passed the very thin surface layer. If this proved to be true, higher temperatures might be employed for carburization, thus forming cases of the required depth in shorter periods of time, but without building up excessive carbon at the surface.

It is unquestionably true that both temperature and concentration gradient affect the velocity of carbon migration, but the first factor has greater influence than the last. Migration proceeds more rapidly as the temperature rises on account of increased atomic mobility, as well as of decreased frictional resistance, due to decreased viscosity of the solid solution.

EXPERIMENTAL

The experiments of the first series were designed to furnish data regarding carburization under conditions involving the two variables, temperature and per cent of ferrosilicon in the mixture.

Steel—The composition of the steel was as follows: Carbon 0.27 per cent, manganese 0.61 per cent, phosphorus 0.014 per cent, sulphur 0.025 per cent, silicon 0.19 per cent. This was in the form of half-inch rods, cut to two-inch lengths. Pieces were cleaned with emery paper before carburizing.

Carburizer—The carburizing material was a commercial carburizing compound. The manufacturers state that in this compound a special grade of carbon is mixed with 20 per cent of barium carbonate and 5 per cent of calcium carbonate, as energizers. The mixtures are ground, bound with molasses into pellet form and dried.

Ferrosilicon—The ferro-alloy used was a 50 per cent ferrosilicon, shown by analysis to contain 0.32 per cent of carbon, a

quantity which is insignificant in such experiments as these. The material was furnished by the Clark Equipment Co., of Buchanan, Mich. In all experiments the ferrosilicon was crushed to pass a 50 mesh sieve.

The cleaned steel specimens were packed in the carburizer, or in the designated mixture of the carburizer with ferrosilicon, using cylindrical nickel-chromium pots, 5 inches long and 3 inches inside diameter, and using one pot for each specimen. For a given temperature of treatment, four pots were placed in an electrically heated muffle, in such positions that the temperature indicated by the thermocouple practically applied to all.

After heating for five hours at the desired temperature the furnace switch was opened and the pieces were cooled in the pots, without removing from the furnace. The cooled pieces were cut at the middle parts and sections were polished and etched with nital for microscopic examination.

Measurement of Case—A 6 \times micrometer eyepiece was calibrated for use with the 14-millimeter objective by use of a stage micrometer, ruled in 0.1 and 0.01-millimeter spacings. Measurements were then made by means of the micrometer eyepiece, eight different readings about the circular case being averaged for the record.

Table I gives the results for this series. In the first column the character of the carburizer is indicated, as follows: C, 100 per cent compound; 10, 20, or 30, compound containing ground ferrosilicon in the per cents indicated. Total depth of case and thickness of the three zones are given in millimeters.

The results indicate that the effect of ferrosilicon admixtures with the carburizing compound is (a) to diminish carbon penetration at the higher temperature and for this time period, (b) to eliminate the hypereutectoid zone of the case, and (c) to widen the hypoeutectoid zone. At the lower temperatures it would seem that ferrosilicon increases the total depth of penetration but as these results have not been confirmed, no particular stress is laid upon them.

The results of treatment with the 20 per cent mixture do not accord with those of other experiments shown in this table, or with those of experiments later reported, and they are therefore to be accepted with question.

Table I
Carbon Penetration in Millimeters in Steel, with and without Ferrosilicon
 Heated for Five Hours at Designated Temperatures

Carburizer	Case Depth			
	At 1742 Degrees Fahr. (950 Degrees Cent.)			
	Total	Hypereutectoid	Eutectoid	Hypoeutectoid
C	1.6	0.2	0.47	0.93
10	1.4	0.0	0.30	1.10
20	1.13	0.0	0.40	0.73
30	1.4	0.0	0.33	1.07
At 1562 Degrees Fahr. (850 Degrees Cent.)				
C	0.74	0.0	0.28	0.46
10	0.64	0.0	0.15	0.49
20	0.90	0.0	0.28	0.62
30	0.70	0.0	0.25	0.45
At 1382 Degrees Fahr. (750 Degrees Cent.)				
C	0.06	0.0	0.00	0.06
10	0.21	0.0	0.00	0.21
20	0.24	0.0	0.00	0.24
30	0.17	0.0	0.00	0.17

Work with Ingot Iron—In all of the remainder of the experiments here reported, Armeo ingot iron was used instead of steel. The presence of exceedingly small amounts of impurities in this material practically eliminates the question of influence of elements other than silicon and carbon, and the fact that the only metallographic constituent is ferrite makes case depth measurements more easy and definite.

Of the three mixtures tried with steel, the one containing 20 per cent of ferrosilicon appeared to show the most pronounced effect and this mixture was used for the remainder of the experiments, with the exception of those in which a paste coating was employed.

After cooling the carburized piece in the box it was, in each experiment, cleaned and the surface examined to determine its superficial condition. It was then cut near the middle and about one-fourth inch of the entire cross section was removed and prepared for microscopic examination of the transverse section of the two end pieces, one was tested for case hardness in the annealed condition, the other being reheated to 1560 degrees Fahr. (850 degrees Cent.) and quenched in water, after which it also was tested for hardness.

Table II
Carburization of Armco Iron
 Heating for Five Hours at 1742 Degrees Fahr. (950 Degrees Cent.).
 Commercial Carburizer Indicated by the Symbol "C"

Carburization	Total	Case Thickness (Millimeters)			Case Hardness (Rockwell)	
		Hyper-eutectoid	Eutectoid	Hypoeutectoid	Annealed	Quenched
R-5, in 50-mesh "C"	1.77	0.50	0.37	0.90	B87	C66
R-6, in 50-mesh "C" with 20% of ferrosilicon	1.67	0.00	0.61	1.06	B87	C60

Carburization at 1742 Degrees Fahr. (950 Degrees Cent.) for Five Hours—In Table II are given the results, so far as carbon penetration and Rockwell hardness are concerned, and Figs. 3 and 4 show the structural characteristics of the annealed case.

The effect of ferrosilicon upon penetration of carbon is seen to be that of somewhat decreasing the total depth of penetration, while widening both eutectoid and hypoeutectoid zones, with total elimination of the zone of free cementite. Inspection of Figs. 3 and 4 shows also that the transition from the second to the third zone is somewhat less abrupt in the case represented by Fig 4.

Both of these results might naturally be expected, if one may assume that carbon absorption is diminished by the presence of ferrosilicon, while carbon migration is left practically unaffected.

Examination of the outer zone shown in Fig. 3 indicates that Armco iron carburizes "abnormally," the ferrite lining around the cementite network being rather pronounced. It may here be remarked that this characteristic was noticed in all of the Armco specimens which were used in these experiments, where a hyper-eutectoid outer case was obtained. Whether or not this point has been observed by others is not known but as Armco iron is made by a basic open-hearth process such a condition might be considered as likely, if it be true that minute quantities of oxygen or of oxides are, as Ehn supposes, responsible for "abnormality."

Effect of Time of Carburization Upon Penetration at 1742 Degrees Fahr. (950 Degrees Cent.)—In order to determine the approximate time during which carburization might be continued without the production of a zone of free cementite, pieces were

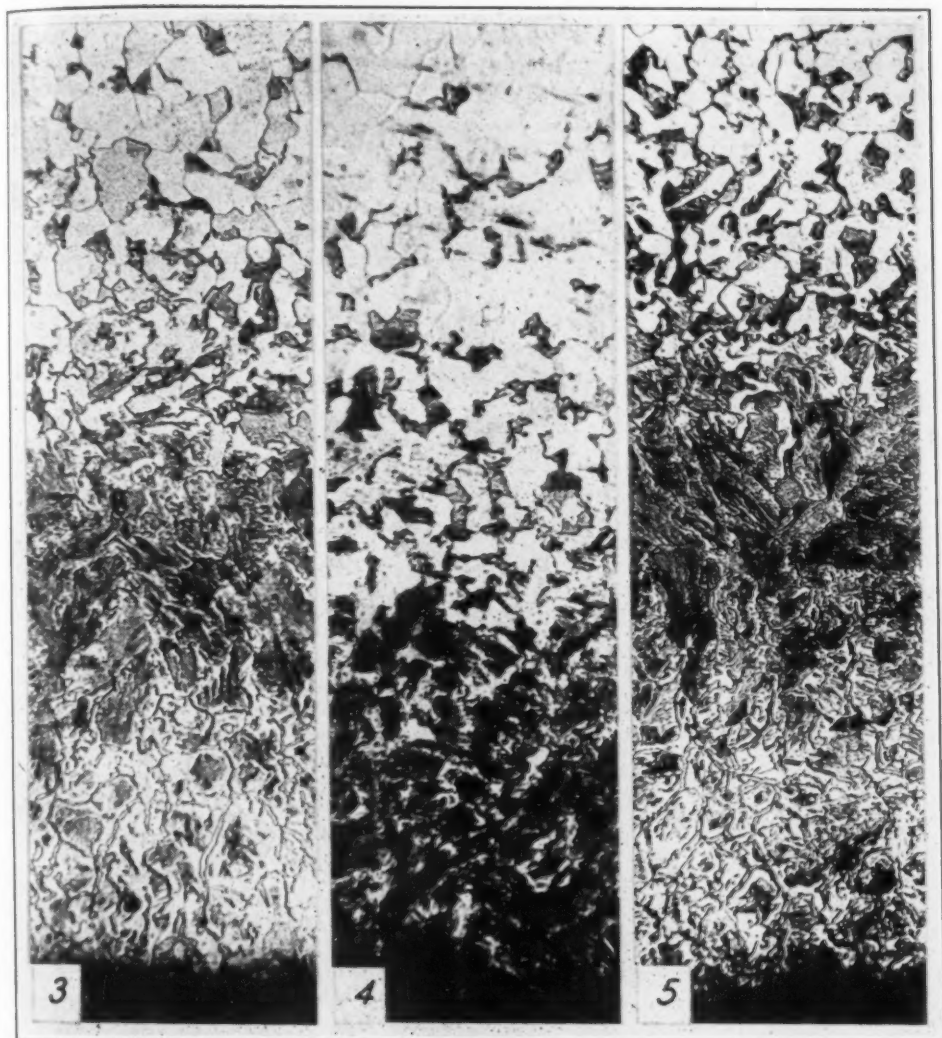


Fig. 3—Photomicrograph of Specimen R-5. Carburized in 50-Mesh Compound for 5 Hours at 1742 Degrees Fahr. (950 Degrees Cent.) $\times 60$. Fig. 4—Photomicrograph of Specimen R-6. Carburized in 50-Mesh Compound with 20 Per Cent of Ferrosilicon for 5 Hours at 1742 Degrees Fahr. (950 Degrees Cent.) $\times 60$. Fig. 5—Photomicrograph of Specimen R-20. Carburized in 8-Mesh Compound for 7 Hours at 1742 Degrees Fahr. (950 Degrees Cent.) $\times 60$.

carburized for five, seven and nine hours, respectively. Check pieces were carburized in "C", although the shortest period of time allowed gave a decided hypereutectoid zone in the cases produced. The commercial carburizer, whether pure or in mixture, was crushed to about 8-mesh size.

It thus appears (a) that at 1742 degrees Fahr. (950 degrees Cent.) carburization with the 20 per cent mixture may be contin-

Table III
Effect of Time of Carburization Upon Penetration and Upon Hardness,
at 1742 Degrees Fahr. (950 Degrees Cent.)

Carburization	Total	Case Thickness (Millimeters)			Case Hardness (Rockwell)	
		Hyper-eutectoid	Eutectoid	Hypoeutectoid	Annealed	Quenched
R-27, in "C" for 5 hours	2.04	0.61	0.43	1.00	B87	C65
R-20, in "C" for 7 hours	2.30	0.66	0.44	1.20	B87	C63
R-64, in "C" with 20% of ferrosilicon for 5 hours	1.84	0.00	0.69	1.15	B85	C63
R-67, in "C" with 20% of ferrosilicon for 7 hours	2.05	0.00	0.73	1.32	B85	C65
R-14, in "C" with 20% of ferrosilicon for 9 hours	2.50	(*)	0.84	1.66	B91	C66

(*) Slightly hypereutectoid over about one third of the case.

ued for about eight hours without the formation of a case containing free cementite, and (b) that a seven-hour treatment gives about the same total depth of case as with unmixed commercial carburizer in five hours, but with the second and third zones making up the entire case, where ferrosilicon is used.

The microscopic structures of case for specimens R-20, R-64, R-67 and R-14, respectively, are shown in Figs. 5, 6, 7, and 8.

Effect of Dilution—There now arises the question as to whether the retarding action of ferrosilicon might not be due to simple dilution of the active commercial carburizer by an otherwise inert material. In order to obtain an answer to this question a fourth series of experiments was conducted. Commercial carburizer was ground to 50-mesh size and a specimen of ingot iron was carburized in this, mixed with 20 per cent of 50-mesh sand. The results are shown in Table IV, in which also are reproduced those of Table II for comparison.

It will be noticed that the penetration from commercial carburizer is less than that shown in Table III, where the carburization was conducted ostensibly under the same conditions. This may

Table IV
Effect of Dilution of Carburizer by Sand Upon Carburization for Five Hours
at 1742 Degrees Fahr. (950 Degrees Cent.)

Carburization	Total	Case Thickness (Millimeters)		
		Hypereutectoid	Eutectoid	Hypoeutectoid
R-5, in 50-mesh "C"	1.77	0.50	0.37	0.90
R-6, in 50-mesh "C" with 20% of ferrosilicon	1.67	0.00	0.61	1.06
R-30, in 50- mesh "C" with 20% of sand	1.57	0.37	0.36	0.84

be due partly to the fact that the carburizer was sized differently, and partly to somewhat different time periods consumed in heating up the furnace and in cooling, factors not under perfect control.

Dilution of the active carburizer by sand reduces the total case depth but this reduction is largely in the outer zone, the second and third zones remaining substantially the same as where no diluent was used. The ferrosilicon mixture, on the other hand, widens the second and third zones, with total elimination of the zone of free cementite. The action of ferrosilicon therefore cannot be ascribed to mere dilution of the essential carburizer.

Use of Silicon Pastes—If only that ferrosilicon which is in the immediate vicinity of the iron is effective, it would seem reasonable to suppose that a surface application of this material would accomplish the same end and that ferrosilicon might be thus conserved by such a modification. Search was therefore made for a suitable paste for this purpose.

Ground ferrosilicon was mixed with water and glucose and with water and dextrin, respectively, and a coating applied to the specimens before carburizing. These pastes adhered well at ordinary temperatures, before and after drying, but after carburization had been completed it was found that the entire paste had crumbled away as soon as the organic material had become charred.

Sodium silicate, in the form of water glass, was tried next. A paste made from 100 cubic centimeters of water glass and 100

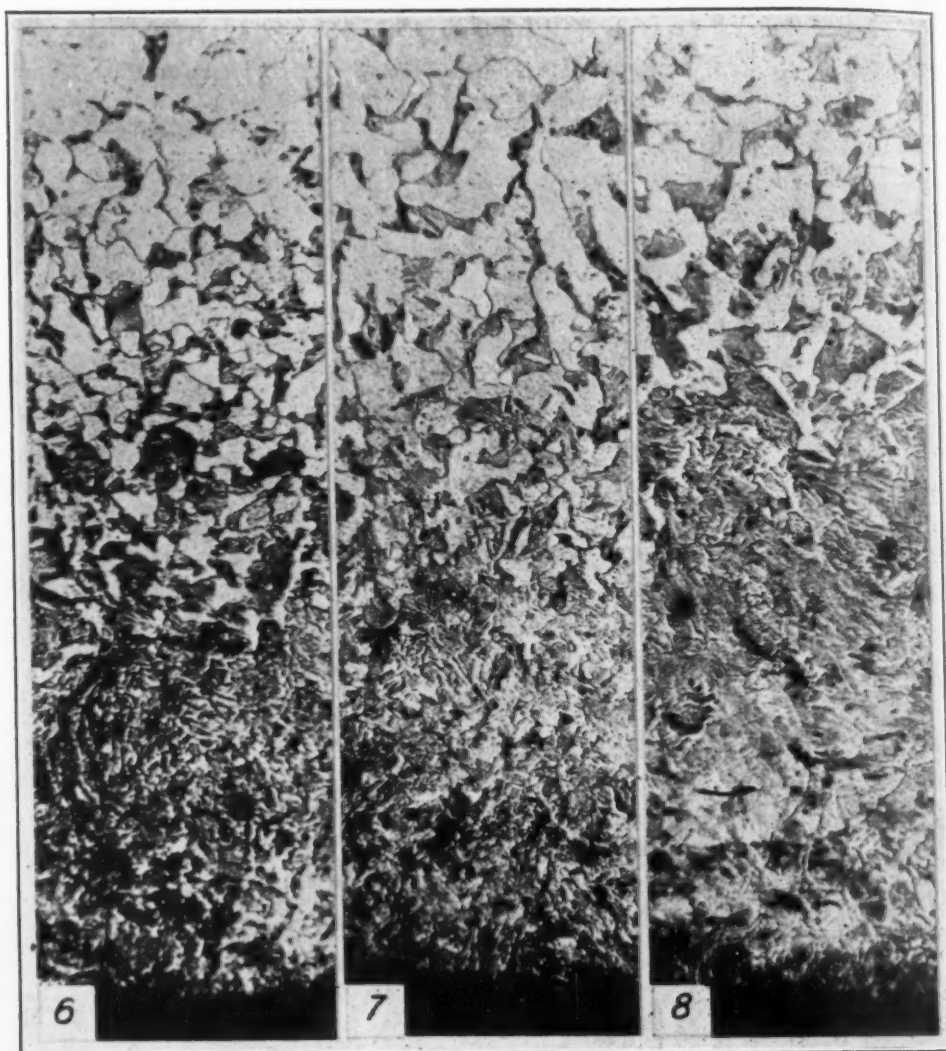


Fig. 6—Photomicrograph of Specimen R-64. Carburized in 8-Mesh Compound with 20 Per Cent of Ferrosilicon for 5 Hours at 1742 Degrees Fahr. (950 Degrees Cent.). $\times 60$. Fig. 7—Photomicrograph of Specimen R-67. Carburized in 8-Mesh Compound with 20 Per Cent of Ferrosilicon for 7 Hours at 1742 Degrees Fahr. (950 Degrees Cent.). $\times 60$. Fig. 8—Photomicrograph of Specimen R-14. Carburized in 8-Mesh Compound with 20 Per Cent of Ferrosilicon for 9 Hours at 1742 Degrees Fahr. (950 Degrees Cent.). $\times 60$.

grams of ground ferrosilicon was found to adhere well and it did not become detached during carburization.

The results of carburization of coated pieces, packed in 8-mesh commercial carburizer, were comparable with those which were obtained when the 20 per cent ferrosilicon mixture was used. After cooling, the paste was found to have been in a semi-fused condition, in some cases, so that it had to be removed by use of

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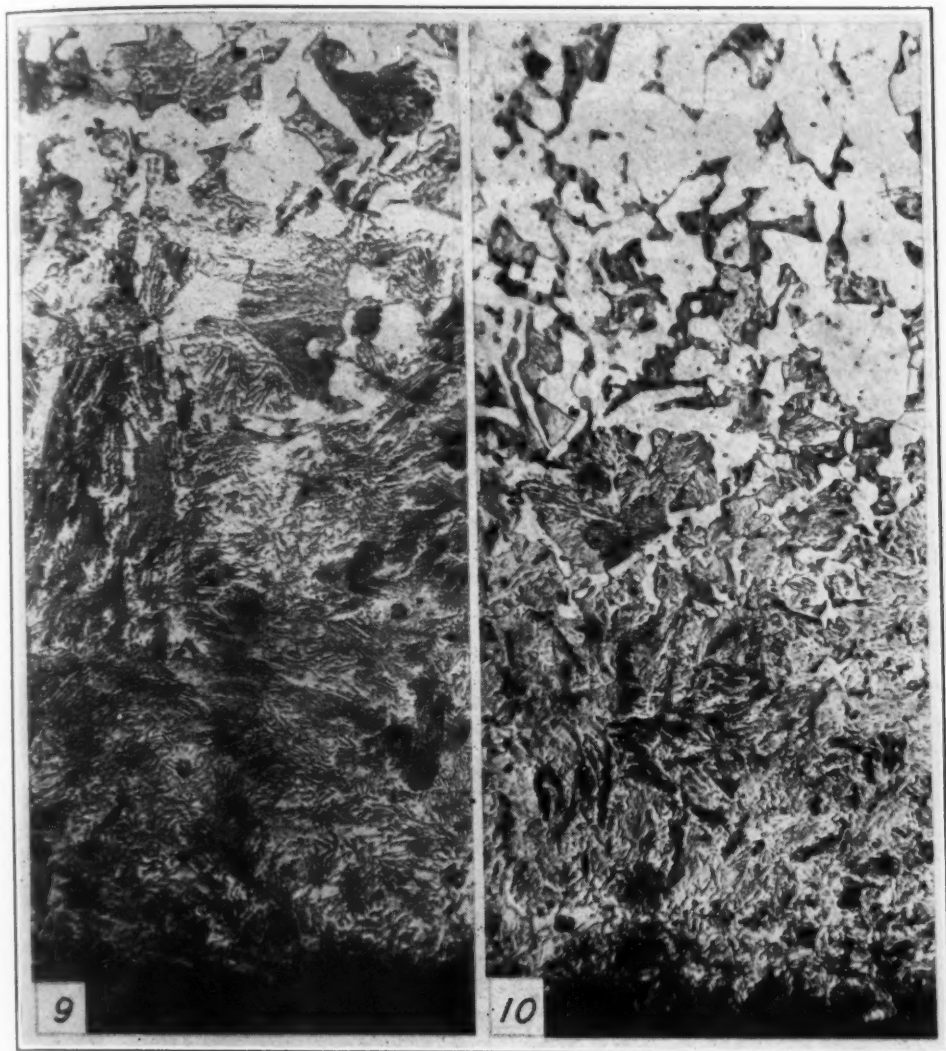


Fig. 9—Photomicrograph of Specimen R-29. Paste Coated, then Carburized in 8-Mesh Compound for 5 Hours at 1742 Degrees Fahr. (950 Degrees Cent.). $\times 144$. Fig. 10—Photomicrograph of Specimen R-68. Paste Coated, then Carburized in 8-Mesh Compound for 7 Hours at 1742 Degrees Fahr. (950 Degrees Cent.). $\times 60$.

emery cloth. This left the surface of the case somewhat spotted and slightly pitted, indicating local and probably uneven silicon penetration. However, the carbon case was found to be even and it is therefore not regarded as likely that silicon had penetrated very far into the specimen, even in possible localities of higher silicon concentration.

In Table V the figures for specimens R-27, R-20, R-64 and R-67 are reproduced for comparison with the measurements upon specimens which were coated with paste before carburization,

Table V
Comparison of Results Obtained by Three Methods of Carburization

Carburization	Total	Case Thickness (Millimeters)			Case Hardness (Rockwell)	
		Hyper-eutectoid	Eutectoid	Hypoeutectoid	Annealed	Quenched
R-29, paste coated, then in "C" for 5 hours at 1742° Fahr.	1.72	0.00	0.63	1.09	B90	C65
R-64, in "C" with 20% of ferrosilicon for 5 hours at 1742° Fahr.	1.84	0.00	0.69	1.15	B85	C63
R-27, in "C" for 5 hours at 1742° Fahr.	2.04	0.61	0.43	1.00	B87	C65
R-68, paste coated, then in "C" for 7 hours at 1742° Fahr.	2.27	0.20	0.65	1.42	B85	C65
R-67, in "C" with 20% of ferrosilicon for 7 hours at 1742° Fahr.	2.05	0.00	0.73	1.32	B85	C65
R-20, in "C" for 7 hours at 1742° Fahr.	2.30	0.66	0.44	1.20	B87	C63

The pearlitic structure of specimen R-29 is shown by higher magnification in Fig. 9. The case depth and distribution for R-68 are shown in Fig. 10.

Carburization, with and without the use of paste, on a single piece—One specimen was dipped, horizontally, into the ferrosilicon-water glass paste, so that the transverse section might show a circular case, one half of which had been formed under the influence of the paste while the other half would be carburized in the ordinary way. This specimen was carburized for five hours at 1742 degrees Fahr. (950 degrees Cent.) in 8-mesh commercial carburizer.

Examination of the transverse section indicated fairly sharply the points where the influence of the ferrosilicon began and ended, the half surface under the paste showing all of the char-

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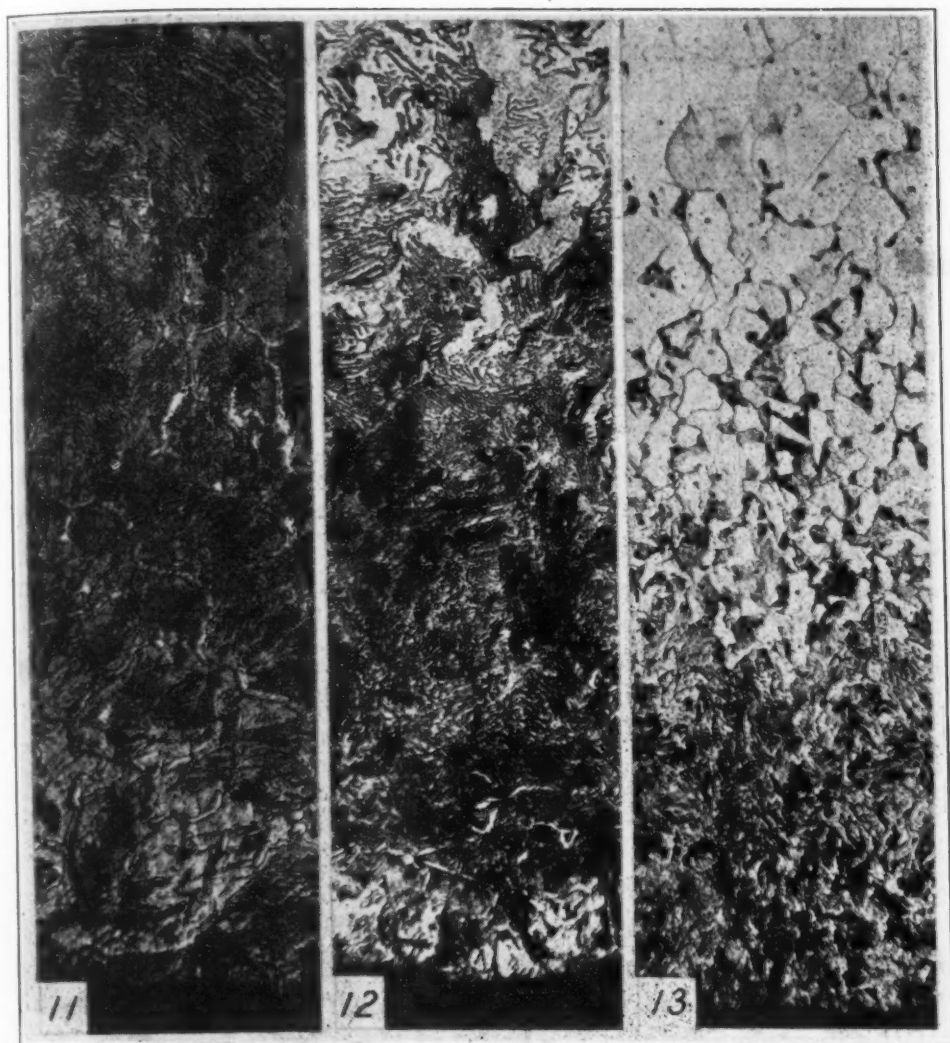


Fig. 11—Photomicrograph of Specimen R-28. This Portion Without Paste Coating. Carburized in 8-Mesh Compound for 5 Hours at 1742 Degrees Fahr. (950 Degrees Cent.). $\times 144$. Fig. 12—Photomicrograph of Specimen R-28. This Portion Paste Coated. Carburized in 8-Mesh Compound for 5 Hours at 1742 Degrees Fahr. (950 Degrees Cent.). $\times 144$. Fig. 13—Photomicrograph of Specimen R-40. Carburized in 8-Mesh Compound for 13 Hours at 1634 Degrees Fahr. (890 Degrees Cent.). $\times 60$.

acteristics already noted for such carburization, while the other half showed the effect normal to the commercial carburizer.

This would indicate that the effect of the ferrosilicon does not carry far, which might be explained either by assuming that the effect is observed only where solid contact of iron and ferrosilicon exists, or that silicon cementation takes place through the medium of some gaseous compounds, unstable and quickly decomposed at

carburization temperatures, or perhaps that both processes of silicon cementation result from such treatment. The latter assumption seems the most reasonable.

Figs. 11 and 12, at somewhat higher magnification, indicate the nature of the outer portions of the case on the two halves of the specimen.

Conditions Necessary for the Production of Similar Cases by Two Methods—In order to produce a case having no free cementite in the outer layer by the use of ordinary, fairly rapid commercial carburizers, it is necessary to use lower temperatures for carburization. This slows carbon migration and a longer time period is required for the production of a case of a given depth. It was found by repeated trials, varying the time and temperature of carburization, that at 1634 degrees Fahr. (890 degrees Cent.) a case could be formed by the use of carburizer "C" only, having no hypereutectoid zone, but that it required thirteen hours at this temperature to obtain the same total case depth as that produced in five hours at 1742 degrees Fahr. (950 degrees Cent.) by either of the methods involving ferrosilicon.

Fig. 13 indicates the structure of the case of specimen R-40, which was carburized in "C" for thirteen hours at 1634 degrees Fahr. and this may be compared with Fig. 6, for carburization in the mixture of "C" with 20 per cent of ferrosilicon, the size of particles of the carburizer being the same in both cases.

Double Cementation—A specimen of Armeo iron was cemented for five hours at 1742 degrees Fahr. (950 degrees Cent.) in ground ferrosilicon. It was then cooled and packed in ground "C" and carburized for five hours at the same temperature. The type of case was the same as that which was produced when mixtures of "C" with ferrosilicon were used. This clearly indicates that ferrosilicon does not act simply as a mechanical obstruction to gaseous diffusion or as a simple diluent, but that the absorbed silicon, small in amount though it probably is, plays some vital part in regulating the absorption of carbon during the process of case carburization.

In Table VI the measurements made upon this case are compared with those for specimen R-64 of Table III. The total case depth is greater than in R-64 but the distribution in the three possible zones is about the same, no free cementite being found in either case.

Table VI
Carburization by Single and by Double Cementation Methods

Carburization	Total	Case Thickness Millimeters		
		Hypereutectoid	Eutectoid	Hypoeutectoid
R-64, in "C" with 20% of ferro-silicon, 5 hours at 1742°F.	1.84	0.00	0.69	1.15
R-62, in ground ferro-silicon for 5 hours at 1742°F., followed by 5 hours in "C" at same temp.	2.01	0.00	0.65	1.36

Silicon Penetration—Specimens R-35 and R-36 were placed in a lathe and turned accurately to a diameter of $\frac{9}{16}$ inch. They were then carburized, R-35 in "C" and R-36 in "C" with 20 per cent of ferrosilicon, both for five hours at 1778 degrees Fahr. (970 degrees Cent.). After cooling in the box, both specimens were lightly polished with emery cloth, cleaned and replaced in the lathe. Layers 0.01 inch in depth were turned off and silicon determined for this layer of each specimen. Specimen R-35 was found to contain 0.033 per cent and R-36, 0.053 per cent of silicon, in this outer layer. No doubt most of the silicon of R-36 was concentrated in considerably higher proportion in the first few thousandths inch near the extreme outer surface.

This result indicates that under the conditions here used, silicon has penetrated only the extreme outer layers of iron, but that even such thin layers of high-silicon iron have so retarded the absorption of carbon as to eliminate the hypereutectoid zone, while permitting undisturbed inward migration of the carbon after absorption.

Bending Tests—Pieces of the same $\frac{5}{8}$ -inch round Armco iron were cut five inches in length, three of these being carburized for bending tests, while a fourth was bent without carburization.

After carburization and cooling in the box, the four test pieces were supported across two $1\frac{1}{4}$ -inch steel rods placed four inches apart, and slow hydraulic pressure was applied through a rounded V-shaped steel bar, placed across the middle of the specimen.

The result of the tests are shown in Fig. 14, methods of pre-

liminary treatment for the respective pieces being indicated in the legend.

The piece which was carburized for five hours at 1742 degrees Fahr. (950 degrees Cent.) broke with the lowest angle of bend, as might be expected, since this method gives a slightly deeper

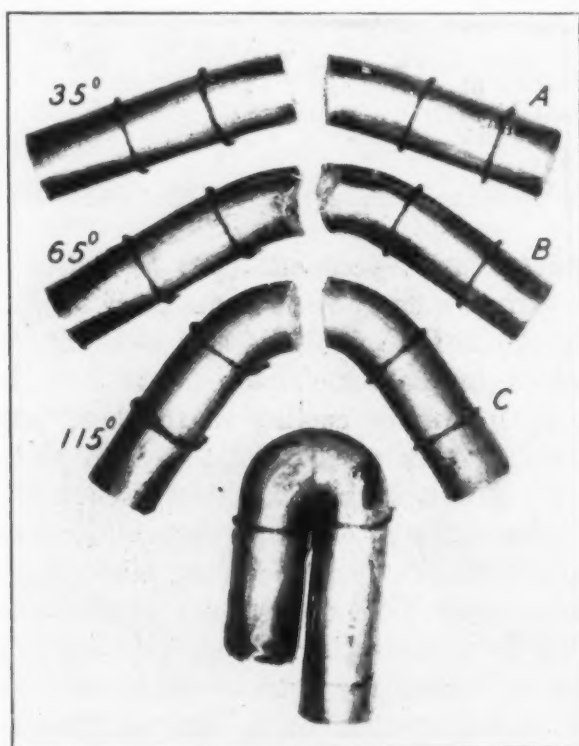


Fig. 14—Photograph of Bend Tests on $\frac{5}{8}$ -Inch Round Armco Iron. (A) Specimen R-43. Carburized in Compound for 5 Hours at 1742 Degrees Fahr. (950 Degrees Cent.). (B) Specimen R-41. Carburized in Compound for 13 Hours at 1634 Degrees Fahr. (890 Degrees Cent.). (C) Specimen R-39. Paste Coated, then Carburized in Compound for 5 Hours at 1742 Degrees Fahr. (950 Degrees Cent.). (D) Untreated. All Carburized Specimens Cooled in the Carburizing Box. $\times \frac{2}{3}$.

case than either of the others, and one which would impart to the outer zone the brittleness due to free excess cementite.

Of the other two, the paste-treated piece showed decidedly better bending characteristics, as evidenced not only by the wider angle through which it bent before fracture, but also by the more even character of the fracture. It will be noted that specimens R-39 and R-41 were carburized by two methods already found to give the same depth and type of case (this was confirmed by

examination after fracture), the bend test therefore giving some idea as to the comparative brittleness of the cases formed by the two methods.

THEORETICAL

It may be assumed that it has been satisfactorily proved by various others that steel and iron will absorb silicon when heated to temperatures below fusion in contact with ferrosilicon or with silicon hydrides, and that silicon in iron or steel will retard cementation by carbon.

The work described in this paper appears to have shown that if ferrosilicon be mixed with a carburizer, or if it be applied to the surface of steel or iron, the latter then being packed in a carburizer and heated, the result is the elimination of the zone of free cementite from the outer case, under time and temperature conditions which would otherwise produce such a zone, but without seriously affecting the case depth.

We have interpreted this result by assuming that surface absorption of silicon has diminished the rate of carbon absorption through the formation of a very thin, high-silicon "fence," but that after the carbon has once passed this obstruction it migrates toward the core, with the migration rate only slightly affected by the reduced carbon gradient. It has then become possible, by the use of ferrosilicon, to duplicate the case depth produced by an ordinary commercial carburizer, simply by raising the temperature of carburization. The higher temperature accelerates carbon migration and shortens the time necessary for the production of a given case depth by more than 60 per cent, at the same time eliminating the brittleness of a hypereutectoid outer case. In these experiments, employing a mixture of ferrosilicon with the carburizer, a rise of 108 degrees Fahr. (60 degrees Cent.) in temperature was sufficient to reduce from thirteen to five hours, the time necessary for the production of a case of given depth without free cementite. If this process, or some modification of it, could be applied in practice, the reduction in time necessary for carburization might become an important item in cost reduction.

The maximum silicon content of the outermost layers of the treated pieces is not known. But the proportion has evidently not been high enough to induce any noticeable increase in grain size or

to cause brittleness of the case, as is evidenced by the results of the bend tests, and there has been no striking or consistent change in surface hardness. The silicon absorption may possibly be uneven, as would be indicated by the slightly spotted character of the surface after carburization. This would be expected if it be true that silicon absorption results from solid contact of ferrosilicon with the iron surface. But this possible unevenness has not been sufficient to cause unevenness in carbon cementation, as the microscopic character of the case in this respect was almost uniformly good.

It is not believed that the depth of silicon penetration has been greater than a few thousandths of an inch, in these experiments. Most of this would be removed in the grinding ordinarily given to parts after case hardening.

The question may well be asked as to the mechanism of silicon absorption. There is no doubt of the fact that contact of solid particles of ferrosilicon with iron will result in silicon absorption at carburization temperatures. But the even effect of a mixture containing only 10 per cent of ferrosilicon (Table I) indicates that such occasional contact has not been entirely responsible for the observed action. It therefore seems likely that some gaseous compound, or compounds, of silicon have played a part in silicon cementation.

Vawter (*) showed that silicon hydride produced some silicon cementation, but his (probably) mixed hydrides were evidently unstable at carburizing temperatures, as shown by the loose coating of silicon over the specimens.

Freshly broken ferrosilicon gives a strong odor, similar to that of silicon hydride. The odor itself might not be considered as conclusive evidence as to the identity of the evolved gases, since acetylene, phosphine and arsine possess similar odors. In fact, evolution of the gases above named, as also of hydrogen, has been assumed.²¹ But it is not believed that the assumption was confirmed and the small amount of carbon (0.32 per cent) contained in the ferrosilicon used in these experiments, as well as the probability that this was all in the graphitic state, precludes the possibil-

*Loc. cit.

²¹Quotation from London "Times": *Journal*, Society of Chemical Industry, Vol. 28, 1909, p. 25

ity of the formation of more than mere traces of acetylene or of other hydrocarbons. There seems little reason to suppose that phosphine or arsine could have been formed in more than traces, if at all.

It appears to be more likely that the gas coming from freshly crushed ferrosilicon is a mixture of the hydrides of silicon (and possibly also hydrogen), generated through slow attack of moisture, as for example:



Magnesium silicide, warmed with water, generates the hydride readily.

As the gas is quite unstable, only that portion which comes into contact with the iron shortly after its formation would be effective in imparting silicon to the surface of the iron, and this might account for the lack of carrying power as shown by the results of carburization of the half-coated specimen.

The authors would like to emphasize the fact that the purpose of this series of investigations was not simply to add one more nostrum to the already large list of "remarkable" carburizing compounds. They have worked with but a single commercial carburizer, and it is realized that the conditions might be considerably changed in case others were used in a similar way. So far, no attempt whatever has been made to place a new process on a basis of commercial practice. But the scientific principles involved seemed of sufficient interest to make some experimental investigation desirable, and the results appear to be worthy of report.

Similar work, involving the use of other ferro-alloys in case-carburization, is in progress in this laboratory.

Acknowledgment—The authors desire to express their appreciation for material supplied without charge by the American Rolling Mills Co., Middletown, Ohio, the Clark Equipment Co., Buchanan, Michigan, and the Rodman Chemical Co., Chicago, and for physical testing to W. E. Dittrich, metallurgist for Inland Steel Co., Indiana Harbor, Ind.

DISCUSSION

Written Discussion: By H. A. Schwartz, manager of research, National Malleable and Steel Castings Co.

The writer's detailed knowledge of the subject matter of Drs. Mahin and Spencer's paper is insufficient to allow his discussion to be anything more than the presentation of a few questions arising out of the authors' work.

Are these results to be interpreted primarily in the light of the decreased solubility of carbon in the presence of silicon? This seems perhaps unlikely for at case carburizing temperatures this solubility would be reduced to negligible amounts by as little as 4 per cent silicon whereas the authors apparently consider that there is a pretty high silicon concentration in the extreme outer zone.

Are there any data as to the variation in carbon content of the outer surface with case carburizing temperatures? There appears to be no evidence in the micrographs leading one to believe that there is a piling up of carbon in the outer layers of iron which have not been affected by silicon, i. e., in those layers slightly below the surface.

It would seem likely that if the action of silicon is through the intervention of a gaseous compound then the stability of the ferrosilicon used is of importance. The authors have used a ferrosilicon richer in that element than is commonly used in melting practice. The high silicon ferrosilicons, especially those around 95 per cent silicon, are known to be particularly unstable, giving off the odor referred to in the paper which somewhat resembles that of acetylene.

The question is in the writer's mind whether anything is known as to any limiting concentration on the low side for the silicon content in ferrosilicon required to produce the results observed and described in the paper.

It is realized that this discussion adds nothing to the authors' presentation but it is hoped that the answers to the questions propounded might perhaps be of some value in interpreting the results and still more in practicing the process if that should prove feasible.

H. W. McQUAID: It seems to me that this method of using ferrosilicon offers us a possible opportunity to do by other methods of carburizing what we are now doing with gas, that is, to get the depth you want, the carburized depth, with a lower carbon case, which gives you a case which will not spall in service. I think that is a very desirable condition. The point that I was worrying about was whether or not this case, after you get it in this way, would be file hard. It looks to me like it might be soft to the file. I was wondering whether Professor Mahin had tried to file any of these cases. The Rockwell hardness is apparently all right.

B. M. LARSEN (Assistant Metallurgist, Bureau of Mines): I would just like to ask Professor Mahin if they made any measurements of carbon gradients on these samples. We have found that in measuring carbon gradients on some steels killed with an excess of ferromanganese and ferrosilicon, and in certain vacuum-melted iron-silicon alloys with other elements such as manganese absent, the hypereutectoid cementite around the boundaries of the grains in the outer zones, did not show up very plainly. In some cases, with as much as 0.6 to 0.8 per cent silicon, we were unable to

see any hypereutectoid cementite boundaries at all, and at the same time we have fairly definite evidence from carbon gradient measurements that there were no appreciable differences in the actual depth of case, and that carbon contents in excess of 1.0 per cent existed in the outer zone. It might be worth while to make some actual measurements of carbon penetration and carbon gradients by actual analyses, just as a matter of checking up and to make the interpretation of the results somewhat more definite. We have found that microscopic examination is not a reliable method of determining depth of carbon penetration.

ROBERT BARRY: In regard to the detection of cracks, I might suggest that by some system of electrical amplification of sound, those cracks, when they occur, can be easily determined.

Authors' Reply to Discussion

DR. MAHIN: I have Mr. Schwartz's written discussion before me. With regard to the question as to whether these results are to be interpreted primarily in the light of the decreased solubility of carbon in the presence of silicon, I see no reason why they should be so interpreted. As a matter of fact, if the time of carburization is prolonged a hypereutectoid case will be produced, so that it isn't a question of reaching a limiting solubility for carbon.

As to whether there are any data as to the variation of the carbon content of the outer surface—and this perhaps will apply also to the question raised by Mr. Larson—we made no determinations of carbon gradient by means of analysis. That, I presume, should and will be done sooner or later. We were simply interpreting the microscopic structure.

Mr. Schwartz speaks of using ferrosilicons with lower silicon content. Up to this time we have necessarily kept the experimental work within quite narrow limits and I have been careful to say we can make no predictions as to what will happen if we change the conditions. We have not used ferrosilicon of lower or higher silicon content than the 50 per cent, although that is undoubtedly a line of work that must be done.

The odor that is given off when we break ferrosilicon is a purely qualitative indication, and I make no pretense of knowing what that material is. I do not believe it is arsine or phosphine, as somebody has suggested, and I do not believe it is acetylene, because there is not enough carbon present to form this compound in appreciable quantities. It seems to me that perhaps hydrides of silicon are formed by the attack of moisture, because no matter how old the ferrosilicon may be, if you break a piece you can get the odor very distinctly.

I might say that in line with these other experiments that we are carrying out, we have planned, at least, the use of some more unstable silicon compounds than the ferrosilicons. Magnesium silicide is entirely too unstable, but some of the silicides, as that of calcium, for example, may give interesting results. I have no notion of what results they will give.

File hardness was tried on these. Naturally, we can't get any quan-

titative results in that way and I can simply say that the case was quite hard, especially on the quenched specimens.

Authors' Written Closure: The point raised by Mr. Larsen is an interesting one. If it be true that, in the proportions present in the case of steels carburized by the method described in this paper, silicon inhibits the separation of free cementite during slow cooling, even when the outer case may be hypereutectoid with respect to carbon, this should be a distinct advantage from the practical standpoint, since the case hardness could thereby be increased without the danger of causing cementite brittleness. Of course the fundamental objection to a hypereutectoid case is in the difficulty in causing reabsorption of cementite after it has once separated.

During the course of the experimental work now in progress, we expect to make more extensive and accurate determinations of actual carbon gradients, as well as of silicon gradients. While the results will not affect the general principle involved, they should help to make more intelligible the mechanism of the carburization under the new conditions.

THE INFLUENCE OF NICKEL ON COMBINED CARBON IN GRAY IRON

BY J. R. HOUSTON

Abstract

The effects of the common metaloids on the amount and form of combined carbon relating to fluidity, temperature and rate of cooling in cast iron are generally well understood. In recent years the claim has been made for nickel that it is a "pearlite builder" in gray iron, and that by its use in a favorable composition, both the amount and structural form of combined carbon may be controlled to a marked degree, thereby giving density to heavy sections and machinability to light sections, which, if true, makes it a valuable tool in the hands of the foundry metallurgist.

THE largest percentage of our castings require mixtures ranging from 1.50 to 2.00 per cent silicon, having a total carbon ranging from 3.60 to 3.75 per cent. The steel content varies from 10 to 40 per cent. We do not find that the metal containing the higher percentage of steel sets more quickly or chills more on light sections within these percentages, if the temperatures of the irons are equal and silicon, sulphur, phosphorus, manganese and total carbon are the same in each case. However, a difference in graphite structure and distribution is observed.

With us, as with most foundries using several mixtures in the day's run, fluidity and rate of cooling are variables causing large variations in combined carbon. In order to try out the claim made for nickel that it controls combined carbon caused by these variables, we decided to try out different percentages of nickel in different mixtures. As for temperature, we melt our iron hot and pour it according to general practice which means that the first mold poured from the ladle is poured from 50 to 200 degrees Fahr. hotter than the last mold. It was therefore decided not to use a pyrometer. Since the ratio of relative cooling rate equals the

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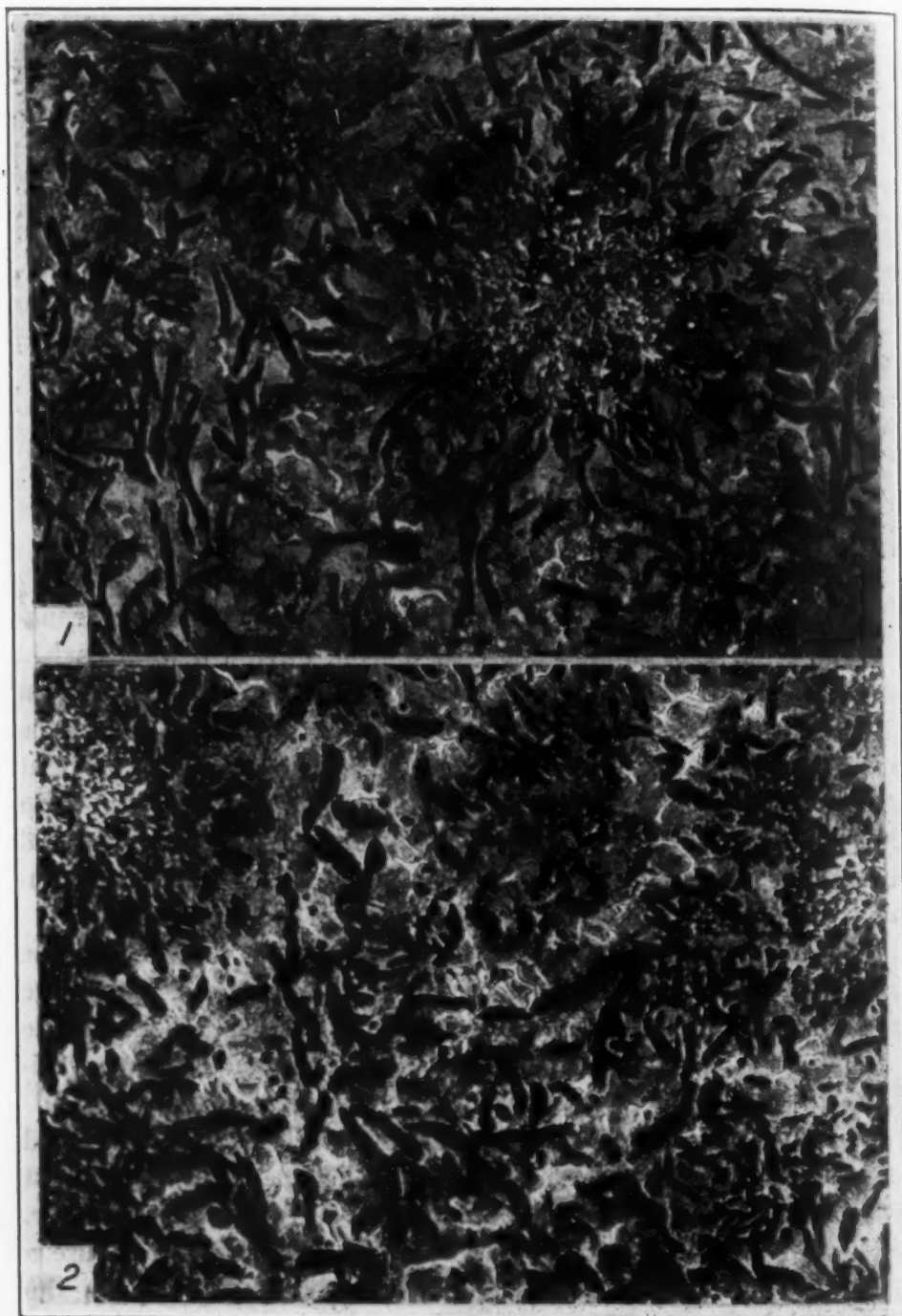


Fig. 1—Photomicrograph of Bar No. 12. $2 \times 2 \times \frac{1}{4}$ Inch Section of Plain Cast Iron Step Bar. Casting Poured Hot. Etched in 2 Per Cent Nital. $\times 150$. Fig. 2—Photomicrograph of Bar No. 13. $2 \times 2 \times \frac{1}{4}$ Inch Section of Plain Cast Iron Step Bar. Casting Poured Cold. Etched in 2 Per Cent Nital. $\times 150$.

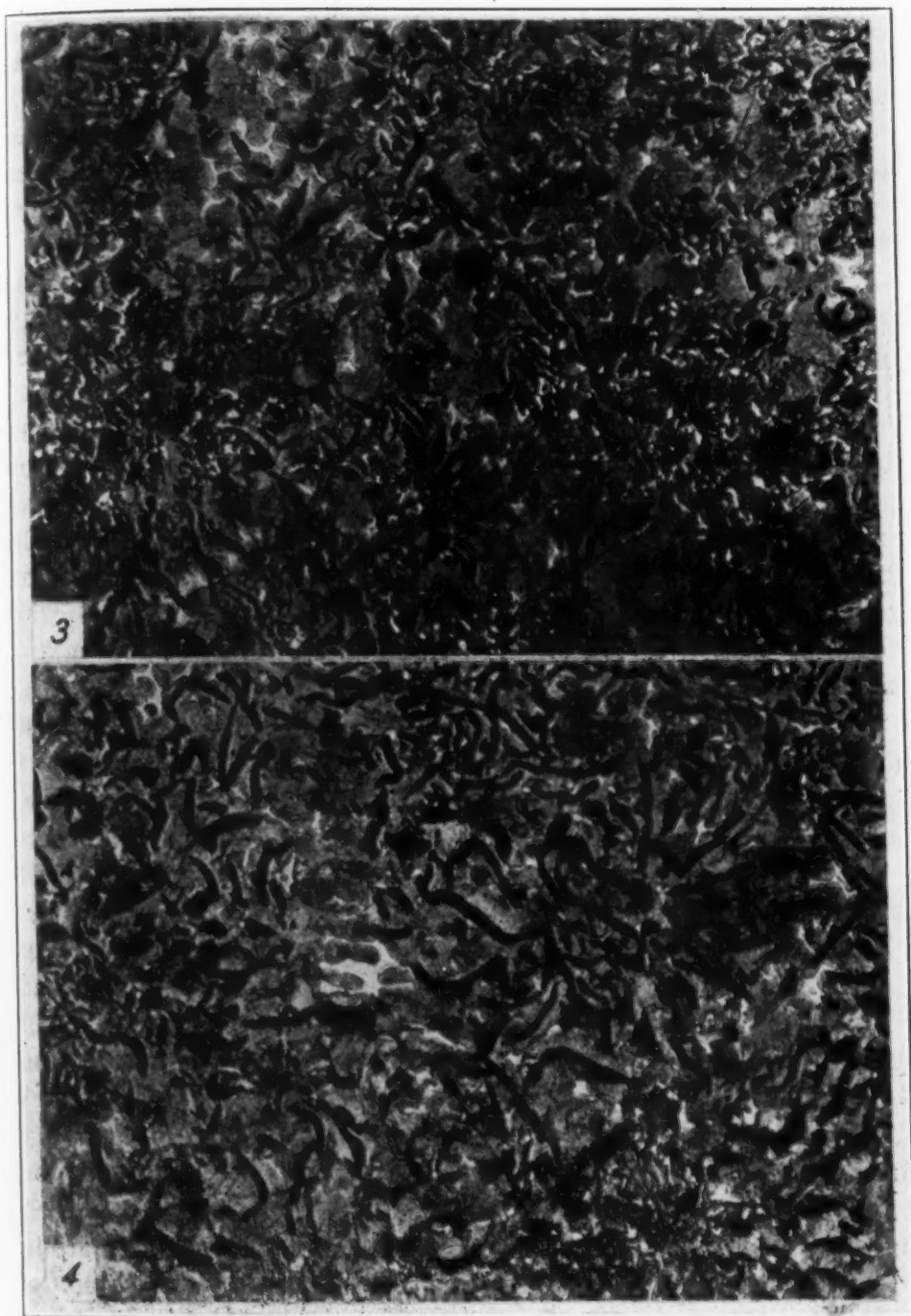


Fig. 3—Photomicrograph of Bar No. 14. $2 \times 2 \times \frac{1}{4}$ Inch Section of Nickel Cast Iron Step Bar. Casting Poured Hot. Etched in 2 Per Cent Nital. $\times 150$. Fig. 4—Photomicrograph of Bar No. 15. $2 \times 2 \times \frac{1}{4}$ Inch Section of Nickel Cast Iron Step Bar. Casting Poured Cold. Etched in 2 Per Cent Nital. $\times 150$.

volume divided by the surface area¹, it was decided to use a step bar pattern having sections 2×2 inch and with steps of the following thickness: 1", $\frac{1}{2}$ ", $\frac{3}{8}$ ", $\frac{1}{4}$ ", $\frac{1}{8}$ "; all gated from the $2 \times 2 \times 1$ inch end so that the metal would in each case, have to flow the full length of the mold to fill the $\frac{1}{8}$ -inch thick section. Charges No. 1 and No. 2 were made up with 30 per cent steel, and charges No. 12 to No. 28, with 10 per cent steel.

We then purposed to mill the sample and make chemical analysis from the step bar in the 1", $\frac{1}{2}$ ", $\frac{3}{8}$ ", $\frac{1}{4}$ " and $\frac{1}{8}$ " sections, using the entire amount of millings so obtained as the sample for total carbon determination, thereby avoiding the possibility of loss of graphite. A heavier cut taken in the same manner, was to be thoroughly mixed and taken for all other determinations except graphite, and represent the composition in that charge. It was thought that this procedure would be more accurate than a sample from a single test piece taken from the receiving ladle to represent the charge. The sample for graphite was to be taken from each thickness section in identical locations and total carbon minus graphitic carbon, equals combined carbon.

However, the combined carbon results so obtained were so much at variance with the structure shown by the photomicrographs, that error was apparent and it was found necessary to determine the total carbon from the same sample lot from which the graphite determination was made; there being as much as 0.11 per cent total carbon difference between the results obtained in the 1-inch section and the $\frac{1}{8}$ -inch section. We are unable to account for the higher total carbon in the light sections and when we had completely exhausted our resources to learn the cause, we sent sample castings to two different laboratories, Kimman and Wheeler, Syracuse, N. Y.; and International Nickel Co., New York City, who checked our results. We have not had the opportunity to investigate this, to us, unusual thing, and have no explanation, at this time, to offer but in our tabulations, we have treated each section of each casting individually for all carbon determination.

In Table I, no examination or comparisons were made of the $2 \times 2 \times 1$ inch sections. In Table II, the $2 \times 2 \times \frac{3}{8}$ inch section was not completed and tabulated because the combined carbon was almost identical with the $2 \times 2 \times \frac{1}{2}$ inch sections. In the same

¹British Cast Iron Research Association Research Report No. 26.

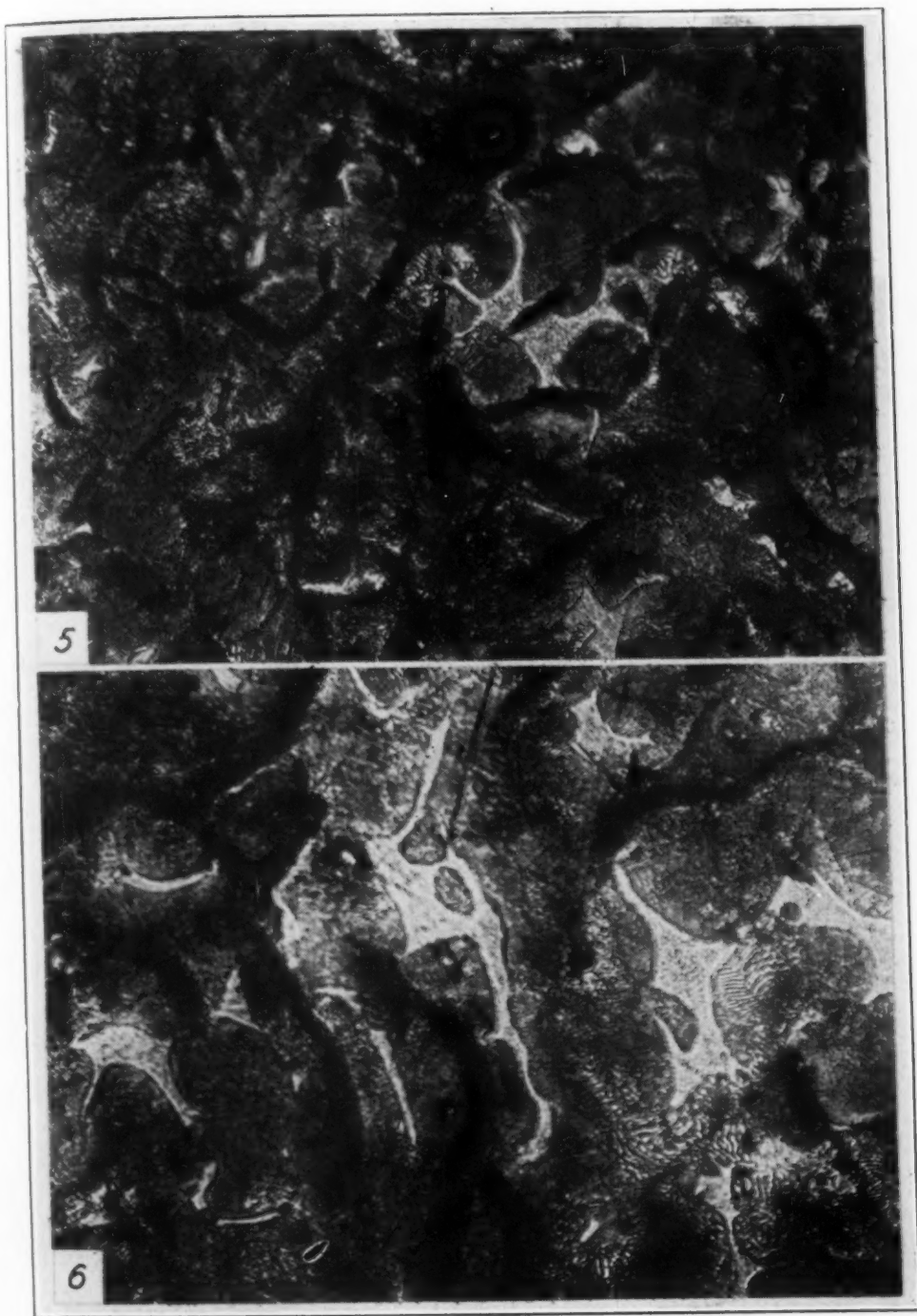


Fig. 5—Photomicrograph of Bar No. 12. $2 \times 2 \times \frac{1}{4}$ Inch Section of Plain Cast Iron Step Bar. Casting Poured Hot. Etched in 2 Per Cent Nital. $\times 500$. Fig. 6—Photomicrograph of Bar No. 13. $2 \times 2 \times \frac{1}{4}$ Inch Section of Plain Cast Iron Step Bar. Casting Poured Cold. Etched in 2 Per Cent Nital. $\times 500$.

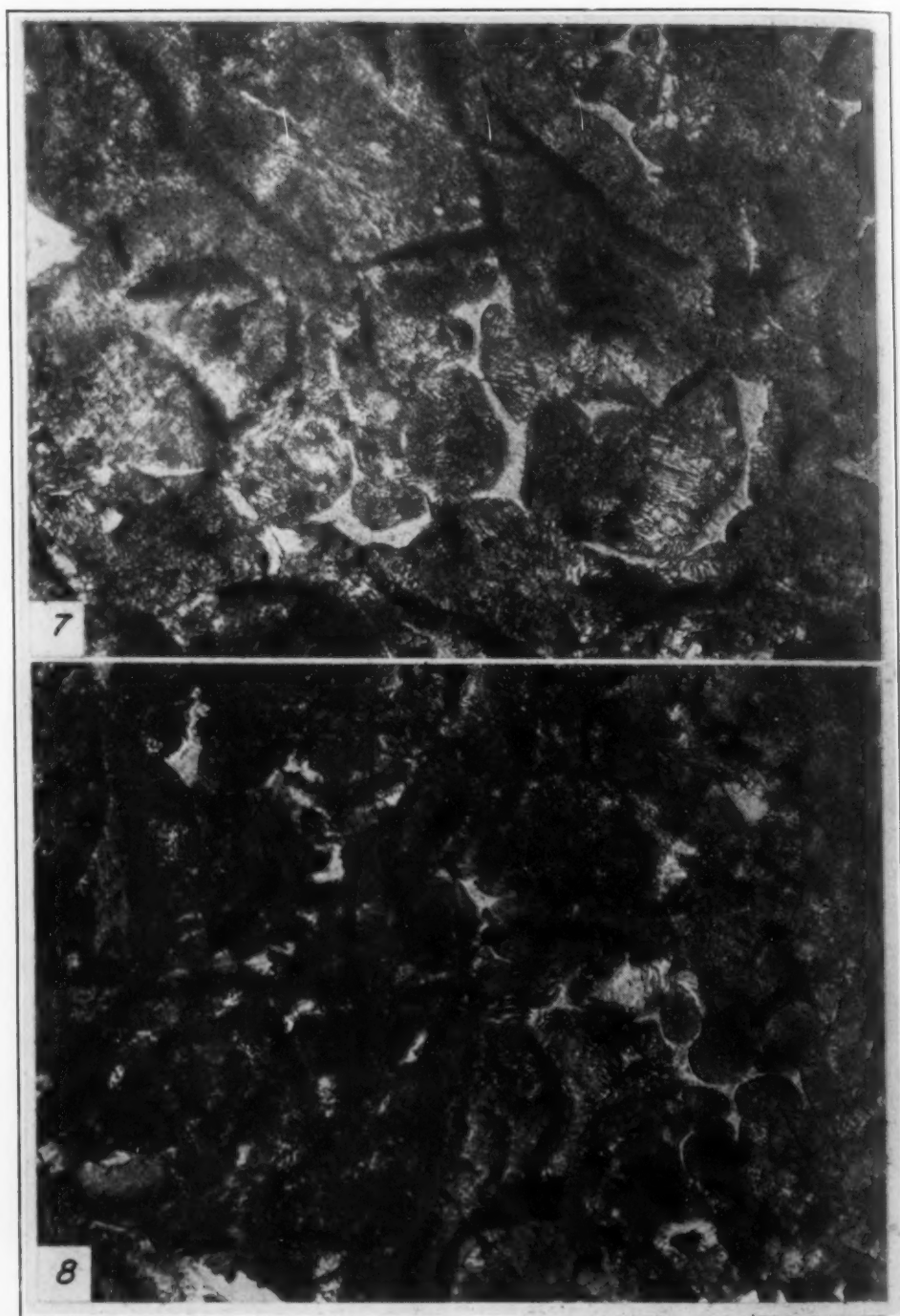


Fig. 7—Photomicrograph of Bar No. 14. $2 \times 2 \times \frac{1}{4}$ Inch Section of Nickel Cast Iron Step Bar. Casting Poured Hot. Etched in 2 Per Cent Nital. $\times 500$. Fig. 8—Photomicrograph of Bar No. 15. $2 \times 2 \times \frac{1}{4}$ Inch Section of Nickel Cast Iron Step Bar. Casting Poured Cold. Etched in 2 Per Cent Nital. $\times 500$.

Table I
Comparison Table—30 Per Cent Steel

Charge No.	Poured	Section, Inches	Si	S	Per Cent P	Mn	Ni	Total Carbon	Graphitic Carbon Per Cent	Com-bined Carbon
1	Hot	2 × 2 × 1/2	1.68	0.080	0.17	0.93	0.00	3.73	3.16	0.57
		2 × 2 × 3/8	.....	.....	.....	.....	.....	3.74	3.10	0.64
		2 × 2 × 1/4	.....	.....	.....	.....	.....	3.76	3.06	0.70
		2 × 2 × 1/8	.....	.....	.....	.....	.....	T.H.S.	.....	.....
	Cold	2 × 2 × 1/2	.....	.....	.....	.....	0.00	3.73	3.19	0.54
		2 × 2 × 3/8	.....	.....	.....	.....	.....	3.74	3.17	0.57
		2 × 2 × 1/4	.....	.....	.....	.....	.....	3.76	3.13	0.63
		2 × 2 × 1/8	.....	.....	.....	.....	.....	T.H.S.*	.....	.....
	Hot	2 × 2 × 1/2	.....	.....	.....	.....	0.88	3.73	3.11	0.62
		2 × 2 × 3/8	.....	.....	.....	.....	.....	3.74	3.10	0.64
		2 × 2 × 1/4	.....	.....	.....	.....	.....	3.76	3.13	0.63
		2 × 2 × 1/8	.....	.....	.....	.....	.....	3.78	3.11	0.67
	Cold	2 × 2 × 1/2	.....	.....	.....	.....	0.88	3.73	3.18	0.55
		2 × 2 × 3/8	.....	.....	.....	.....	.....	3.74	3.19	0.55
		2 × 2 × 1/4	.....	.....	.....	.....	.....	3.76	3.18	0.58
		2 × 2 × 1/8	.....	.....	.....	.....	.....	3.78	3.17	0.61
2	Hot	2 × 2 × 1/2	1.67	0.078	0.16	0.91	0.00	3.73	3.16	0.57
		2 × 2 × 3/8	.....	.....	.....	.....	.....	3.74	3.10	0.64
		2 × 2 × 1/4	.....	.....	.....	.....	.....	3.76	3.06	0.70
		2 × 2 × 1/8	.....	.....	.....	.....	.....	T.H.S.*	.....	.....
	Cold	2 × 2 × 1/2	.....	.....	.....	.....	0.00	3.73	3.19	0.54
		2 × 2 × 3/8	.....	.....	.....	.....	.....	3.74	3.17	0.57
		2 × 2 × 1/4	.....	.....	.....	.....	.....	3.76	3.13	0.63
		2 × 2 × 1/8	.....	.....	.....	.....	.....	T.H.S.	.....	.....
	Hot	2 × 2 × 1/2	.....	.....	.....	.....	1.13	3.66	3.06	0.60
		2 × 2 × 3/8	.....	.....	.....	.....	.....	3.70	3.07	0.63
		2 × 2 × 1/4	.....	.....	.....	.....	.....	3.73	3.09	0.64
		2 × 2 × 1/8	.....	.....	.....	.....	.....	3.73	3.08	0.65
	Cold	2 × 2 × 1/2	.....	.....	.....	.....	1.13	3.66	3.14	0.52
		2 × 2 × 3/8	.....	.....	.....	.....	.....	3.70	3.16	0.54
		2 × 2 × 1/4	.....	.....	.....	.....	.....	3.73	3.18	0.55
		2 × 2 × 1/8	.....	.....	.....	.....	.....	3.73	3.13	0.60

*T.H.S. Too hard to sample.

table, sections 2×2×1/8 inch were not analyzed and tabulated because some of the castings did not fill out the mold and would not yield representative values.

A hot 50-pound hand ladle was filled and immediately poured into the proper mold. This was tabulated as "hot". The same ladle of iron was then allowed to stand for about a minute and the casting tabulated as "cold" was poured. The same procedure was followed with the nickel iron except that the predetermined amount of nickel was added to the bottom of the ladle in the form of a low melting nickel-iron-silicon alloy containing 92 per cent nickel.

We looked for a greater and more consistent increase in combined carbon between the "hot" and the "cold" castings than was

Table II
Comparison Table—10 Per Cent Steel

Charge No.	Poured	Section, Inches	Si	S	Per Cent P	Mn	Ni	Total Carbon	Graphitic Carbon Per Cent	Com- bined Carbon
12	Hot	2 X 2 X 1	1.73	0.058	0.24	0.63	0.05	3.65	3.14	0.51
		2 X 2 X 1/2	.....	.....	.....	.....	.....	3.68	3.09	0.59
		2 X 2 X 1/4	.....	.....	.....	.....	.....	3.78	3.13	0.65
	Cold	2 X 2 X 1	.....	.....	.....	.....	0.05	3.65	3.22	0.43
		2 X 2 X 1/2	.....	.....	.....	.....	.....	3.68	3.21	0.47
		2 X 2 X 1/4	.....	.....	.....	.....	.....	3.78	3.10	0.68
	Hot	2 X 2 X 1	.....	.....	.....	.....	0.30	3.65	3.33	0.32
		2 X 2 X 1/2	.....	.....	.....	.....	.....	3.68	3.34	0.34
		2 X 2 X 1/4	.....	.....	.....	.....	.....	3.78	3.41	0.37
	Cold	2 X 2 X 1	.....	.....	.....	.....	0.30	3.65	3.35	0.30
		2 X 2 X 1/2	.....	.....	.....	.....	.....	3.68	3.36	0.32
		2 X 2 X 1/4	.....	.....	.....	.....	.....	3.78	3.38	0.40
16	Hot	2 X 2 X 1	1.76	0.060	0.26	0.65	0.09	3.68	3.21	0.47
		2 X 2 X 1/2	.....	.....	.....	.....	.....	3.70	3.14	0.56
		2 X 2 X 1/4	.....	.....	.....	.....	.....	3.74	3.13	0.61
	Cold	2 X 2 X 1	.....	.....	.....	.....	0.09	3.68	3.13	0.55
		2 X 2 X 1/2	.....	.....	.....	.....	.....	3.70	3.11	0.59
		2 X 2 X 1/4	.....	.....	.....	.....	.....	3.74	3.10	0.64
	Hot	2 X 2 X 1	.....	.....	.....	.....	2.73	3.68	3.19	0.49
		2 X 2 X 1/2	.....	.....	.....	.....	.....	3.70	3.19	0.51
		2 X 2 X 1/4	.....	.....	.....	.....	.....	3.74	3.22	0.52
	Cold	2 X 2 X 1	.....	.....	.....	.....	2.73	3.68	3.19	0.49
		2 X 2 X 1/2	.....	.....	.....	.....	.....	3.70	3.20	0.50
		2 X 2 X 1/4	.....	.....	.....	.....	.....	3.74	3.24	0.50
20	Hot	2 X 2 X 1	1.81	0.078	0.31	0.70	0.08	3.59	3.08	0.51
		2 X 2 X 1/2	.....	.....	.....	.....	.....	3.62	3.07	0.55
		2 X 2 X 1/4	.....	.....	.....	.....	.....	3.64	3.02	0.62
	Cold	2 X 2 X 1	.....	.....	.....	.....	0.08	3.59	3.09	0.50
		2 X 2 X 1/2	.....	.....	.....	.....	.....	3.62	3.08	0.54
		2 X 2 X 1/4	.....	.....	.....	.....	.....	3.64	2.99	0.65
	Hot	2 X 2 X 1	.....	.....	.....	.....	2.22	3.59	3.04	0.55
		2 X 2 X 1/2	.....	.....	.....	.....	.....	3.62	3.05	0.57
		2 X 2 X 1/4	.....	.....	.....	.....	.....	3.64	3.07	0.57
	Cold	2 X 2 X 1	.....	.....	.....	.....	2.22	3.59	3.04	0.55
		2 X 2 X 1/2	.....	.....	.....	.....	.....	3.62	3.06	0.56
		2 X 2 X 1/4	.....	.....	.....	.....	.....	3.64	3.05	0.59
24	Hot	2 X 2 X 1	1.60	0.086	0.22	0.59	0.00	3.49	2.86	0.63
		2 X 2 X 1/2	.....	.....	.....	.....	.....	3.53	2.84	0.69
		2 X 2 X 1/4	.....	.....	.....	.....	.....	3.57	2.82	0.75
	Cold	2 X 2 X 1	.....	.....	.....	.....	0.00	3.49	2.84	0.65
		2 X 2 X 1/2	.....	.....	.....	.....	.....	3.53	2.84	0.69
		2 X 2 X 1/4	.....	.....	.....	.....	.....	3.57	2.78	0.79
	Hot	2 X 2 X 1	.....	.....	.....	.....	2.65	3.49	2.92	0.57
		2 X 2 X 1/2	.....	.....	.....	.....	.....	3.53	2.93	0.60
		2 X 2 X 1/4	.....	.....	.....	.....	.....	3.57	2.95	0.62
	Cold	2 X 2 X 1	.....	.....	.....	.....	2.65	3.49	2.89	0.60
		2 X 2 X 1/2	.....	.....	.....	.....	.....	3.53	2.93	0.60
		2 X 2 X 1/4	.....	.....	.....	.....	.....	3.57	2.95	0.62
28	Hot	2 X 2 X 1	1.76	0.077	0.29	0.64	0.00	3.60	2.99	0.61
		2 X 2 X 1/2	.....	.....	.....	.....	.....	3.63	2.96	0.67
		2 X 2 X 1/4	.....	.....	.....	.....	.....	3.64	2.86	0.78
	Cold	2 X 2 X 1	.....	.....	.....	.....	0.00	3.60	3.02	0.58
		2 X 2 X 1/2	.....	.....	.....	.....	.....	3.63	2.98	0.65
		2 X 2 X 1/4	.....	.....	.....	.....	.....	3.64	2.90	0.74

Charge No.	Poured	Section, Inches	Si	S	Per Cent P	Mn	Ni	Total Carbon	Graphitic Carbon Per Cent	Com- bined Carbon
Hot		2 × 2 × 1	.....	.....	.....	.....	1.95	3.60	3.09	0.51
		2 × 2 × 1½	.....	.....	.....	.....	.....	3.63	3.10	0.53
		2 × 2 × ¼	.....	.....	.....	.....	.....	3.64	3.13	0.51
Cold		2 × 2 × 1	.....	.....	.....	.....	1.95	3.60	3.10	0.50
		2 × 2 × 1½	.....	.....	.....	.....	.....	3.63	3.10	0.53
		2 × 2 × ¼	.....	.....	.....	.....	.....	3.64	3.10	0.54

obtained, but which may be accounted for partly by the personal equation in pouring and a possible difference in moisture and permeability of the sand. However, the results obtained by us seem to establish definitely the fact that as little as 0.30 per cent of nickel² narrowed the difference in combined carbon in 1-inch section and ¼-inch section to 0.10 per cent in the nickel iron poured "cold" compared to 0.25 per cent in plain iron poured "cold" and that it actually reduced the combined carbon uniformly in all sections, indicating that that percentage of nickel lowered the combined carbon by graphitization similar to the action of silicon.

In Charge No. 1, containing 0.88 per cent nickel, nickel iron poured "hot" showed a slight increase in combined carbon in the 1-inch section over the plain iron but the poured "cold", gave results almost identical to those in the plain iron. The ⅛-inch section in both "hot" and "cold" poured plain irons, were too hard to machine while the nickel irons in the same sections were machinable due to the fact that the combined carbons were below the carbon eutectoid point. Charge No. 2 having the same base as Charge No. 1 only containing 1.13 per cent nickel, shows the same characteristics slightly intensified. As the percentage of nickel increased to 2.73 per cent, the difference in combined carbon content in the 1-inch section and the ¼-inch section becomes less. See Table II. Also the difference of combined carbon between the poured "hot" and poured "cold" in the nickel irons were materially flattened out.

The accompanying photomicrographs (Figs. 1 to 8) show the representative structural differences.

DISCUSSION

Written Discussion: By E. L. Roth, foundry engineer, Steel Sales Corp., Chicago.

²See Charge No. 12, Table II.

The equalizing of the combined carbon produced by adding nickel to a casting containing both light and heavy sections as shown by the excellent data in this paper, has a very important practical significance which has not been mentioned. This is the tendency to reduce warping and cracking due to internal strains.

A good illustration of this is a piston casting which has a light wall with a comparatively heavy section in the ring grooves and the pin bosses. After the casting has solidified, graphitization goes forward at a rate dependent on the cooling rate of the section in question. In a plain cast iron more graphite is precipitated in the heavy section than in the light section because of its slower cooling rate. This means a different linear expansion for both sections and sets up a compressive or tensile stress at the juncture of the two sections.

When the castings are machined and ground a certain percentage show small hairline cracks in the piston skirt, or are out of round. This is due no doubt to the fact that the skirt metal section which is now much thinner is incapable of withstanding the stresses developed in cooling as shown by the widely different percentages of combined carbon in the sections in question. The cracking can be overcome by annealing the pistons but this breaks down all of the combined carbon and leaves a very soft ferrite matrix containing enlarged graphite particles.

One large engine manufacturer has practically eliminated this trouble by adding 0.75 per cent of nickel to the proper base composition in his pistons, thereby producing a very nearly uniform combined carbon in the light and in the heavy section.

The results obtained in this paper have a widespread practical value which will undoubtedly be recognized by engineers who want castings with a uniform structure in all sections and which can be obtained by them by specifying the proper nickel content.

Written Discussion: By J. S. Vanick, International Nickel Co., N. Y.

It is evident in a little study of this paper that the author deserves our expression of appreciation for the painstaking analytical work revealed in his data.

In examining the separate points which he makes, one of the first, pointing out the fact that the total carbon content of a thin section of a casting is higher than that in a thicker section of the same casting, has been confirmed in analysis made at our laboratories upon castings similar to those he used. We have found no substantial explanation for this. A theoretical one which at least agrees with the analytical facts, suggests that the decrease in carbon in the thicker sections is due to an exhalation of carbonaceous gas from the solidifying or solidified castings, and the longer period which the thicker section requires to cool permits it to exhale more gas, thereby lowering its total carbon content. This explanation is not supported at present by any experimental data.

In examining the effect of nickel on the combined carbon contents of the castings, I am going to take some liberties with the data, merely to show a graph typical of the results in the table. Taking the first set of

combined carbons for the plain and nickel cast irons, a glance at Fig. 1 shows that as the sections of the plain iron become thinner, the combined carbon increases rapidly and I have indicated its probable course into high values, say as much as 3.5 per cent combined carbon, such as might be expected from solid white iron, when the section thickness becomes infinite as it would on a corner of the thin casting. A similar curve from the nickel cast iron shows a fairly constant amount of combined carbon. What relation does this increase in combined carbon have to the properties of the iron? The Figs. 6 and 8 in the author's paper answer this in showing an increased quantity of hard iron carbide prevailing in Fig. 6, in this case enough to account for nearly 0.50 per cent more combined carbon. A similar result has frequently been demonstrated in our laboratories by the appearance of fractures of the thin sections of wedge bars, as illustrated in Fig. 2. In this illustration the influence of nickel in clearing

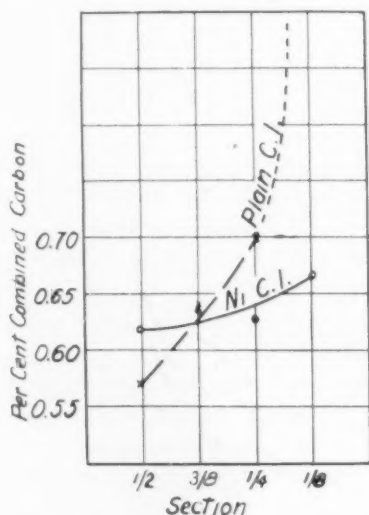


Fig. 1—Curves Showing Combined Carbon in Plain vs. 0.88 Per Cent Nickel Cast Iron (Both Poured Hot).

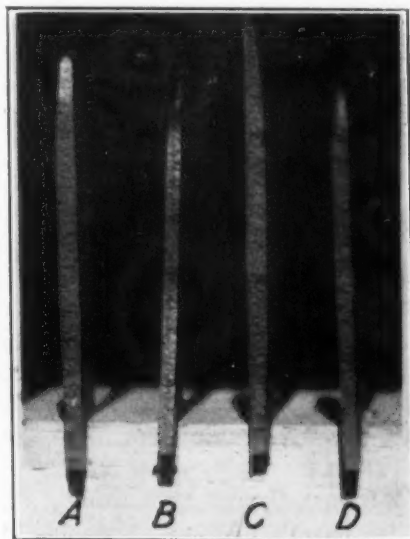


Fig. 2—Photograph Showing Nickel Clearing Thin Sections of Mottled Spots or Chilled Fin.

- A Plain—Hot.
- B Plain—Cold.
- C 2 Per Cent Nickel—Hot.
- D 2 Per Cent Nickel—Cold.

out the white iron edge and also the mottled spots in the thin section is apparent. The mottled spots, which are frequently of microscopic dimensions, are detrimental on account of their intense hardness, to the machinability and wearing properties of the iron and produce in it an increased hardness that is not uniform but from its structural character really a composite of hard particles imbedded in a softer matrix. Where a uniform hardness is frequently used as an index of the strength and constancy of the properties of the iron, it is evident that the uniformity in the combined carbon content in irregular sections of the alloyed iron indicates a corresponding uniformity in its physical properties.

The question might be asked as to why other graphitizing elements such as silicon do not accomplish the same result. The answer to this has been discussed in an earlier paper*. Briefly, it points out the property which nickel exercises in decomposing the iron carbide without appreciably reducing the combined carbon content which normally is obtained in a plain cast iron. In fact, in some cases, nickel actually increases the combined carbon content where the quantity of alloy used is large enough.

Oral Discussion: By C. P. Vauclain: I just thought I would make a few remarks. I have heard so much about nickel, heard so much here about nickel, and we have had considerable experience with nickel in making castings, but so far we have not derived any benefit by the use of nickel.

During the course of our experiments with nickel we have found that an excess of nickel promotes the formation of graphite to a considerably greater extent than silicon. We find that by adding the nickel in the ladle we get a turbulency in the ladle, causing a bubbling up, or a draft is formed, what we call a kish, on the ladle, and in analyzing that kish we find that about 25 or 30 per cent of it is silicon, with about 7 to 10 per cent nickel that has been run off.

Now, in making these castings, we find that our loss is doubled immediately and in machining our castings, we found that we had several spots which condemned the castings, and in breaking into those spots we found the crystalline formation similar to the so-called ferrosilicon which you get in lumps, very similar to it in appearance. However, it didn't occur to us at that time to analyze the crystalline formation within those spots. It would have been very interesting had we done so.

We also found that that kish formation on the ladle continued for quite a considerable time. For instance, you could take it up to the shop and skim it again, after taking it away from the cupola, and you could pour a casting and turn around and skim it again, and pour two or three castings and still the kish would form.

Then, we found that in melting over this iron, for instance, we ran about one per cent nickel, and you melt the iron over in the cupola, melt nothing but this iron, and the natural tendency for the iron is to form its true chemical combination in the cupola, it will combine and absorb the various elements which naturally go to constitute its real chemical formation, and we found that the nickel present in there dropped down to about 0.50 per cent, and the silicon ran up from an average in the castings, we were averaging about 1.50 to 1.60 per cent and it ran up to 1.78 or 1.80 per cent. And the sulphur, most peculiar of all, which is characteristic you have noticed in a lot of researches that have been made, where you run one certain element up to an extreme, another goes along with it, and the sulphur ran up to 0.35 per cent. Where you have too much sulphur, the natural tendency is to run into hardening, since sulphur is one of the best hardeners that you have for cast iron, it is your only natural hardener.

*See reprint No. 499, American Foundrymen's Association, 1925, "Nickel and Nickel-chromium in Cast Iron" by J. S. Vanick and T. H. Wickenden.

That showed to us what we believed, that we were not forming a true chemical metal when we were adding that metal to the ladle, and there was some doubt in our minds whether all that metal is properly fused and diffused throughout the mass, when you consider the metal, nickel or nickel shot that you get, has a higher fusion point than the so-called molten iron which comes out of the cupola.

Reference has been made here to pouring castings hot and pouring them cold in just the period of a minute. Well, a mere minute is what I might call an infinitesimal time when you consider molten iron. It would be much more characteristic and much more beneficial in making these experiments to note the temperatures exactly with a very carefully recording pyrometer or a sight pyrometer. We find that the temperature of the metal at the time at which it is poured has more to do with the characteristic of true cast iron than anything else that you can put in the iron.

Now, it is a question in our minds as to just what proportions of alloys to add to cast iron to get the true chemical combination, and until such time as we know what our chemical combination is, we are only sort of playing around like the apothecary shops used to do years ago, they would put a pinch of snuff in and a drop of this and a drop of that and call it a sure cure for all ills. I feel that we should not wax enthusiastic over the wonderful properties of nickel until we know its true characteristics. At the present time I do not think we know what nickel does to cast iron. They say that nickel has a greater affinity for carbon than the iron, and, naturally, it must have an affinity, but just what does it form? Does it form an iron-nickel carbonate or does it separate the carbon from the iron and form an iron silicate? No one really knows yet, and until such time as we know definitely, I don't think we really can guarantee the results of any alloy.

Author's Reply to Discussion

J. R. HOUSTON: The frankness of Mr. Vaucelain's discussion of his experience with nickel in cast iron brings out very clearly a fact which I trust all of us should appreciate. It is not a "cure-all" or a panacea for all gray iron troubles. There are many conditions that insidiously creep into the best regulated foundry practices.

All of the things Mr. Vaucelain has discussed have happened perhaps many times in almost every foundryman's experience even when no alloying metal was used or contained in the iron. The presence of 25 to 50 per cent silica which he terms as "silicon," together with perhaps 60 to 65 per cent of iron and a few per cent of nickel does not mean that the alloy was the cause of a formation of slag. Many such slags have been analyzed showing only the silica and iron in about the same proportion and have been traced to ladles that have not been thoroughly dried, as many fire clays do not give off all their moisture until they have been heated above a red heat for a considerable time. Doubtless the work mentioned was particular; otherwise nickel would not have been required and for this reason it is most likely that extra precaution was taken to have a clean ladle for pouring the work, which in

(Continued on Page 169)

Educational Section

These Articles Have Been Selected Primarily For Their Educational
And Informational Character As Distinguished From
Reports Of Investigations And Research

THE CONSTITUTION OF STEEL AND CAST IRON SECTION II—PART VI

By F. T. SISCO

Abstract

The present installment, the sixth of the present series, takes up in an introductory manner the hardening of steel. First, the operations of heating for hardening and holding at the hardening temperature are discussed. This is followed by a description of that fundamental concept;—the effect of the speed of cooling upon the location of the lower or A_{r1} transformation point, which, from the standpoint of stable equilibrium, marks the phase change from austenite to pearlite. This paves the way for a description of the constituents martensite, troostite, and sorbite and a discussion of theories of hardening and tempering which will appear in subsequent installments.

IN the previous installment we analyzed the metallurgical term "hardness", and after discussing the conflicting meanings placed upon this important word, defined it as the resistance of a metal or alloy to permanent deformation. In general there are three kinds of hardness. The first and, perhaps, the most important, is the hardness imparted to a metallic alloy, such as steel or duralumin, by thermal treatment, resulting in high strength, high resistance to indentation—recognizable by a high Brinell hardness number—and in most cases by great resistance to machin-

This is the fifteenth installment of this series of articles by F. T. Sisco. The several installments which have already appeared in TRANSACTIONS are as follows: June, July, August, September, November, 1926; January, February, April, June, August, October, 1927; February, April, June, November, 1928.

The author, F. T. Sisco, a director of the society, is chief of the metallurgical laboratory, Air Corps, War Department, Wright Field, Dayton, Ohio.

ing. The second is the hardness imparted to a metal or metallic alloy by cold work, often termed strain hardness; and resulting in a high tensile strength and relatively low ductility, but not resulting in a high Brinell number nor great resistance to machining. The third kind of hardness is the hardness of some alloys, such as high nickel or high manganese steels, which we have called austenitic hardness; a hardness distinguished only by great resistance to machining, but not characterized by a very high tensile strength nor a high Brinell hardness number.

It is well known that failure in pure metals takes place by movement of crystal particles along numerous planes of easy slip. If failure is due to easy slip it is quite clear that to increase the hardness it is only necessary to increase the resistance of the metal to slip.

In a previous discussion we have seen that chemical compounds, solid solutions, eutectic alloys or amorphous metal are, in general, harder than pure crystalline metals. In addition, a metal or alloy containing small grains is usually harder than one containing only large grains. This is due to the fact that in the chemical compound, solid solution, eutectic alloy, or small grained structure, planes of easy slip are fewer or absent altogether, or the atomic bonds are stronger.

If a chemical compound, eutectic alloy or solid solution is introduced into a pure metal, it is evident that the hardness of the metal will be increased. Likewise, if amorphous metal is introduced or formed within a pure metal, the hardness will be increased. In addition to these conditions increased hardness may be caused by the resistance of the slip plane itself, and it is especially evident, when particles, inherently hard in themselves, act as keys in the slip planes.

The hardness imparted to a metallic alloy by thermal treatment is the hardness most familiar to the steel worker. When we heat a piece of high carbon steel to a bright red heat and quench it in cold water it becomes very hard and strong. But for the fact that certain steels can be hardened by thermal treatment our civilization could not have possibly advanced to its present industrial perfection. Without heat treatment the automobile would cost many times what it costs today; and there are some who say that without heat treatment the automobile, as well as other outstanding examples of our present day industrial civiliza-

tion, would be unknown. Try to picture building an automobile without tool steels!

In the present and succeeding installments we will view the hardening and tempering of steel by thermal treatment, first of all discussing the operation of hardening; that is, how we harden a piece of steel. After we have learned how steel is hardened and tempered we will make an effort to learn why it hardens; trying to understand just what is going on inside the metal during the hardening and tempering operations; in other words, trying to find a cause for the effect. The hardening of steel is a phenomenon that is well understood practically, but not so well understood theoretically. We know the effect, we know exactly what will happen when we quench a piece of high carbon steel from a bright red heat into cold water, but we are not so sure of what is going on inside the metal during this operation. A number of theories have been advanced; each has many brilliant adherents; but agreement is, as yet, sadly lacking. The only thing that can be done is to take up the theories of hardening one by one, understanding the fundamentals underlying each, examining critically but withholding final judgment as to their relative worth, pending more conclusive proof.

The operation of hardening consists of three distinct steps: (1) heating to the hardening temperature; (2) holding at that temperature for the proper time; and (3) cooling from the hardening temperature.

HEATING FOR HARDENING

The operation of hardening consists essentially of heating an iron-carbon alloy containing less than 1.70 per cent carbon to a temperature slightly above the transformation range, holding at this temperature just long enough so that the piece is heated through and then extracting the heat at a rate depending upon the required properties.

As has been discussed in past installments, when an iron-carbon alloy containing less than 1.70 per cent carbon is heated through the upper critical range, the alpha iron undergoes allotropic change to gamma iron. This is a definite structural change and involves a re-arrangement of the atoms from the body-centered lattice of the alpha iron to the face-centered lattice of the gamma iron. Carbon or iron carbide is almost completely

insoluble in alpha iron but is readily soluble in gamma iron. As soon as the alpha iron is transformed the gamma iron starts to dissolve the cementite (or carbon, as the case may be).

After the upper critical point has passed— Ac_3 for low carbon steels, $Ac_{3.2}$ for medium carbon steels, and $Ac_{3.2.1}$ for high carbon steels—all of the iron carbide is in solution in the gamma iron and we have the metallographic constituent known as austenite.³⁷ The carbon, as elemental carbon or as iron carbide, as the case may be, is in solid solution, atomically dispersed in the gamma iron.

In heating for hardening we place the steel in a furnace, heat it slowly and uniformly until all of the alpha iron is transformed to the gamma state and all of the carbon or iron carbide has gone into solution in the gamma iron. These constitutional changes take place only in and above the transformation range. If a piece of steel is heated to any point below the transformation range—1000 degrees Fahr., for example—and quenched from this temperature, it will not harden appreciably. At this temperature, which is below the transformation range, the alpha iron has not changed to gamma iron, nor has any of the carbon gone into solution.

The two prerequisites for hardening the iron-carbon alloys are, therefore: (1) the material must be heated to, or above, the temperature at which the alpha iron changes into gamma iron; and (2) the carbon or iron carbide must go into solution in this gamma iron.

It is evident from this that in order to harden by thermal treatment, the iron-carbon alloy must contain an appreciable amount of carbon. Hardening power is conferred upon iron by carbon, and the more carbon present (up to a certain limit) the greater the hardening power. Very low carbon steels cannot be hardened appreciably; on the other hand, steels containing between 0.85 and 1.50 per cent carbon give the maximum hardness when rapidly cooled from above the transformation range.

Steel expands when heated. If a piece of steel is too rapidly or not uniformly heated, as sometimes happens when a large, or irregular-shaped section of cold material is placed in a red hot furnace, severe distortion or even cracking may occur. For this

³⁷This constituent has been described and illustrated in a former installment. *TRANSACTIONS*, Vol. 12, October, 1927, page 656.

reason heating for hardening should be sufficiently slow, so that the heat is absorbed uniformly by the material. Many specifications for hardening outline the proper heating cycle for specific sections.³⁸

HOLDING AT THE HARDENING TEMPERATURE

Hardening temperatures for carbon steels have been given in a former installment.³⁹ As a rule, they are usually the same as the annealing temperatures. In general, carbon steels are heated to some 50 to 100 degrees Fahr. (20 to 50 degrees Cent.) above the $A_{c_{3.2.1}}$ line for hardening eutectoid and hypereutectoid steels, or above the $A_{c_{3.2}}$ line for hardening hypoeutectoid steels. For steels containing 0.85 to 1.25 per cent carbon, 1400 to 1450 degrees Fahr. (760 to 790 degrees Cent.) is the customary hardening range. Large sections are ordinarily heated to somewhat higher temperatures than small sections.

The same precautions necessary in heating and holding the steel at temperature in the annealing operation apply to hardening. Above the transformation range grain growth of the austenite begins. This grain growth is dependent upon the temperature and the time. The higher the temperature and the longer the time that the material is held at this temperature, the faster the grains will grow. Hence in order to avoid grain growth and its accompanying weakness it is essential that in hardening, the steel be heated just high enough and just long enough, so that all constitutional changes will take place. The change from alpha to gamma iron is probably extremely rapid; the solution of the carbon or the iron carbide, however, takes time, consequently sufficient time must be allowed so that this solution is complete.

The time for holding the various steels at the hardening temperature has been worked out in practice and is now a part of many heat treatment specifications. For example, in the HANDBOOK of the American Society for Steel Treating it is directed that die blocks shall be heated for hardening one hour for each inch of cross section or diameter and held at the hardening temperature for one-fifth of the heating time.

After the steel is held at the hardening temperature for the

³⁸For example, see the HANDBOOK, American Society for Steel Treating. 1928 edition, pages 99, 111, 112, etc.

³⁹TRANSACTIONS, American Society for Steel Treating, Vol. 13, February, 1928, page 308. See also the HANDBOOK, American Society for Steel Treating. 1928 edition, page 95.

proper time it is removed from the furnace and cooled. The cooling may be at varying rates, depending upon the properties required. Water, oil or air are the common quenching media. The efficiency of the various quenching media and the effect of the size of the section treated have been studied extensively by Janitzky, French, Klopsch, Scott, and others, and much accurate information is available concerning the operation of quenching in water, oil, air or other media.

In taking up the operation of hardening we are, however, not so much interested in the practical side as we are in the theoretical side; we do not care so much how steel is hardened as why it hardens. We will try to find a cause for the effect. The fact that a piece of high carbon steel becomes very hard and brittle when quenched from a red heat in cold water is not so interesting to us at the present moment as is the reason why it becomes so hard and brittle.

Before discussing what goes on in the steel when it is quenched and tempered it is necessary, first of all, to take up the effect of the cooling rate on the position of the lower transformation point (i. e., Ar_1 or $Ar_{3.2.1}$) and, while viewing the change in the position of this transformation point when cooling is accelerated, become, at the same time, familiar with the three metallographic constituents present in hardened and tempered steels—martensite, troostite and sorbite.

When the conditions under which these constituents are formed is understood, and their structure has been described and illustrated, then we can discuss more intelligently what these constituents are, what causes them to be formed and what is their constitution.

RATE OF COOLING AND FORMATION OF SORBITE

Recent investigations, both in this country and abroad, have shown conclusively that the position of the Ar_1 point is lowered by increasing the speed of cooling. In our discussion of annealing we learned that when a steel containing approximately 0.90 per cent carbon is cooled slowly from a high temperature there will be no structural change until a temperature of approximately 1290 degrees Fahr. (700 degrees Cent.) is reached. At this point, the austenite, which is already of eutectoid composition, undergoes

change into pearlite, which, as we have seen, is an aggregate consisting of parallel plates or lamellæ of ferrite and cementite. In the case of hypoeutectoid or hypereutectoid steels, the change begins at the $Ar_{3.2}$ or Ar_{cm} point, as the case may be, with the rejection of the excess ferrite or cementite by the austenite and ends at Ar_1 by the transformation of the remaining austenite, which is now of eutectoid composition, into pearlite. This is the normal change and occurs when the steel is cooled slowly and is passing from a condition of stable equilibrium above the transformation range to a condition of stable equilibrium below that range.

Now, if cooling is somewhat accelerated through the transformation range, we find that a structural condition results that is different from the laminated pearlite characteristic of a slowly cooled steel. We can no longer identify the distinct lamellæ or plates of ferrite and cementite; we have, instead, a granular structure, in which the ferrite and cementite can be identified with great difficulty, if at all. This structure, resulting from slightly accelerated cooling, is known as sorbite, and is frequently encountered in high carbon steels of relatively small cross section that have been cooled from above the transformation range in air.

If we investigate carefully the thermal change taking place when cooling is slightly accelerated, we will find that the lower transformation point, $Ar_{3.2.1}$, where the austenite changes to pearlite, is no longer at 1290 degrees Fahr. (700 degrees Cent.), but is somewhat lower than this. In speeding up the cooling, in order to form sorbite, we have lowered the temperature at which the austenite-pearlite transformation would take place if the steel had been slowly cooled.

In addition to the change in structure, readily apparent with a microscopic examination, the physical properties have also changed. The steel has a higher tensile strength, higher Brinell hardness and lower ductility as measured by the elongation. In slightly accelerating the cooling through the transformation range three characteristics of the steel have been effected: (1) the structure has been changed from the typical laminated appearance of the pearlite to the granular appearance of the sorbite; (2) the properties have been altered, as is evidenced by higher strength, greater Brinell hardness and lower elongation; and (3) the Ar_1 point has been lowered appreciably.

RATE OF COOLING AND FORMATION OF TROOSTITE

If cooling through the transformation range is still more accelerated a structural condition will result that is different from pearlite and sorbite. This structure is known as troostite and occurs in many hardened or hardened and tempered high carbon steels, but usually associated with either sorbite or martensite. Under the microscope it appears normally as dark colored, irregular-shaped areas or nodules, presenting a half granular, half amorphous appearance. The structure of this constituent will be described in detail later.

Troostite usually can be detected in a heat treated bar of medium high carbon steel by means of a file. If such a bar is heated to 2000 degrees Fahr. at one end, quenched in cold water, and then tested with a file, there will be an area near the end which cannot be scratched. This is martensite. A little further along the bar will be an area where the steel can be just slightly marked by the file. This is troostite. Still further along the bar the file will cut in easily. This is sorbite and pearlite.

In physical properties steel containing principally troostite will be harder, have higher tensile strength and will be less ductile (lower elongation) than a steel containing practically all pearlite or sorbite. It is virtually impossible to give specific properties for troostite because, as we shall see later, troostite is variable in composition and structure and, consequently, variable in properties. It is, like sorbite, more nearly a structural condition than a definite metallographic constituent as is ferrite or pearlite.

As a rough estimate we may assign the following Brinell hardness numbers to troostite and compare it with the other metallographic constituents:

Ferrite	80-100
Pearlite	150-200
Sorbite	200-300
Troostite	300-400
Martensite	400-700

These figures are at best only an approximation. The hardness will vary widely, depending upon the amount of carbon present, and whether the constituent is contaminated by the presence of small undetected amounts of another constituent, for example, martensite together with troostite, or sorbite together with troostite or with granular pearlite.

If the thermal changes taking place in the steel while cooling to form troostite are investigated it will be found that the position of the Ar_1 point has been lowered still more than when sorbite was produced. Instead of occurring at 1290 degrees Fahr. (700 degrees Cent.) the normal temperature for the austenite-pearlite transformation, the Ar_1 point now occurs at approximately 1100 degrees Fahr. (600 degrees Cent.), or nearly 200 degrees lower than the normal.

This is shown graphically in Fig. 45, reproduced from Sauveur.⁴⁰ The letters, P. S. T. M. and A., are, of course, symbols

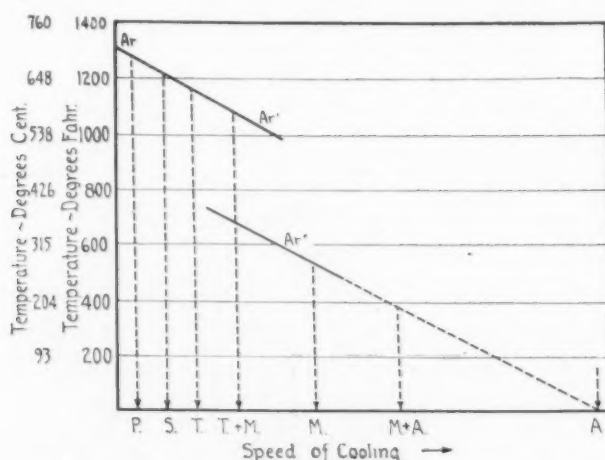


Fig. 45—Curves Showing Speed of Cooling vs. Critical Point and Temperature.

for pearlite, sorbite, troostite, martensite and austenite. The speed of cooling is plotted along the horizontal ordinate, the faster cooling rates extending proportionally to the left of the vertical temperature ordinate. This graph shows the effect of cooling speed on the austenite-pearlite transformation point ($Ar_{3.2.1}$ or Ar_1). From Fig. 45 it is evident that if a high carbon steel is cooled very slowly the Ar_1 transformation occurs at its normal temperature of 1290 degrees Fahr. Now, if cooling is speeded up the temperature of the Ar_1 transformation is lowered along the line $Ar-Ar'$ (Fig. 45), until with the cooling rate necessary to form troostite the temperature of the transformation has been lowered to approximately 1100 degrees Fahr. (590 degrees Cent.).

RATE OF COOLING AND FORMATION OF MARTENSITE

If the cooling rate is accelerated only slightly above that

⁴⁰Metallography and Heat Treatment of Iron and Steel, 1926. Fig. 191, page 214.

necessary to form troostite, a new transformation point makes its appearance. This point occurs at a much lower temperature and is known as Ar'' . It first appears at a temperature of approximately 660 degrees Fahr. (350 degrees Cent.). This point marks the formation of the metallographic constituent martensite. When both Ar' and Ar'' are present, both troostite and martensite will be found in the microstructure.

Now, if the speed of cooling is increased still more, the upper or so-called Ar' point disappears and the lower or Ar'' point is the only one present. This lower point, which has increased in intensity, now occurs at a still lower temperature, about 570 degrees Fahr. (300 degrees Cent.). The result of a cooling so accelerated that Ar'' is the only transformation point present, is a structure consisting wholly of martensite.

The Ar'' point marks the transformation from austenite to martensite, and the speed of cooling necessary to cause the disappearance of the Ar' point and the appearance of the Ar'' point is called the critical speed of quenching.

If the cooling speed could be infinitely increased, the temperature at which Ar'' occurs would be depressed below atmospheric temperature, with the result that no transformation would take place, and austenite would be retained in the steel at normal temperature.

Most authorities consider that the two points, Ar' and Ar'' , are due to a splitting up of the Ar point by rapid cooling. Portevin and Garvin assert that at Ar' troostite forms at the boundaries of the austenite grains; then at Ar'' the central portions of the grains are transformed into martensite.

The properties of martensite naturally vary with the amount of carbon in the steel. Ordinarily we are accustomed to thinking of martensite in connection with a quenched medium-high or high carbon steel. For such a steel in the martensitic condition the ultimate strength and hardness will be high, much greater than for steel in the troostitic condition, and the ductility will be low. Every steel man knows the great brittleness of high carbon tool steel as quenched and not yet tempered.

SUMMARY OF THE EFFECT OF SPEED OF COOLING ON THE TRANSFORMATION RANGE AND STRUCTURE

Summing up the effect of the speed of cooling upon the

position of the lower transformation point, Ar_1 , we find that: (1) when a sample of steel containing an appreciable amount of carbon—0.60 to 0.90 per cent, for example—is cooled very slowly, the Ar_1 transformation takes place at its normal temperature, 1290 degrees Fahr., resulting in a structure consisting principally of laminated pearlite. (2) If this steel is cooled at a slightly accelerated rate, the Ar_1 transformation is lowered slightly. The structure resulting from this slightly accelerated cooling is known as sorbite. (3) Now, if the steel is cooled at a still more accelerated rate, the Ar_1 point is lowered still more, along the line $Ar-Ar'$, Fig. 45, to a temperature of approximately 1100 degrees Fahr., and troostite is formed. (4) If cooling is still more accelerated a separate transformation point, known as Ar'' , occurs at approximately 660 degrees Fahr. This point marks the formation of martensite. (5) When the steel is cooled at such a rate that both Ar' and Ar'' are present, the structure will consist of both troostite and martensite. (6) If cooling is still more rapid, the Ar'' increases in intensity and occurs at a lower temperature and at the same time the Ar' point disappears. (7) If cooling is accelerated to a point where the heat is extracted almost infinitely fast the Ar'' point may be lowered below atmospheric temperature. If this happens we have no transformation taking place, and the structure is austenite.

From this discussion it is clear that by regulating the speed of cooling it is possible to produce a structure consisting of pearlite, sorbite, troostite, martensite, or even in some cases, austenite. It is also evident from this discussion and from an examination of Fig. 45, that the speed of cooling may result in a structure consisting of part laminated pearlite and part granular pearlite, part pearlite and part sorbite, part sorbite and part troostite, part troostite and part martensite, and part martensite and part austenite. It is relatively easy to produce a heterogeneous structure. For example, if we quench a 2-inch round bar of high carbon tool steel from a high temperature in cold water, it is possible to have martensite near the surface of the bar and pearlite at the center. In the area between the surface and center there will be troostite and sorbite. Examining a cross section of this bar should reveal the change in structure from martensite at the edge to pearlite at the center.

(1) In other words, the normal transformation at the Ar point is from austenite stable above this point, to pearlite stable below this point. If cooling is accelerated this normal transformation is retarded with the result that the transformation point is lowered from 1290 degrees Fahr. to atmospheric temperature, and this thermal change is accompanied by a series of transition constituents ranging from granular pearlite through sorbite, and troostite to martensite.

Therefore, if cooling is accelerated we have as a result a structural condition relatively unstable; one tending inherently to return to stability at the first opportunity. The faster the cooling rate through the lower transformation point, the more unstable the resulting structure. Thus, it is evident that of the three constituents already described, sorbite is the most stable, and martensite the most unstable. This will be enlarged upon further in our discussion of theories of hardening.

THE INFLUENCE OF NICKEL ON COMBINED CARBON IN GRAY IRON

(Continued from Page 157)

itself is highly commendable but which may have been the cause of his difficulty. Also, some foundry irons carry a high percentage of graphite that does not enter into combination with the iron during the process of melting, regardless of the presence of alloys. These irons always show a large amount of kish just as described by Mr. Vauclain, and as the iron cools the kish formation increases and no amount of skimming seems to remove all of it.

Whether the nickel is added in the ladle or in the cupola as a part of the charge, has no effect on the kish formation. It is simply what a foundryman of the "old school" would express as an iron being "too rich," and the base composition should be adjusted. I am, however, not in agreement with Mr. Vauclain's idea in regard to what he calls "the true chemical combination in gray cast iron" because I am of the opinion that such a thing is impossible, due to the fact that there is a continual change from the time the iron is melted and poured until it has passed through the critical range in its cooling, which breaks up many of the original chemical combinations and forms new ones. For this reason an iron that is highly satisfactory for one classification of casting is entirely unsuitable for another.

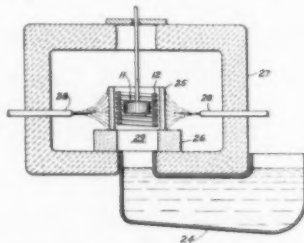
I quite agree with Mr. Vauclain that we should not become over enthusiastic about the wonderful properties of nickel or any other alloy until we understand just how they function in different compositions and under different conditions. In fact, to set forth some of these conditions and compositions and learn whether the results were both uniform and consistent was the objective in conducting the tests which have served as a basis for this paper.

Reviews of Recent Patents

By NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City—Member of A. S. S. T.

1,687,656, Oct. 16, 1928, Heat Treating Method, Walter John Brown, of Davenport Park, England, Assignor to Westinghouse Electric and Manufacturing Company, a corporation of Pennsylvania.

This patent describes a heat treating method by the use of a high frequency induction coil 12, which is used to heat a pinion 11 disposed within the coil, which coil may be water cooled, or which may be disposed within a tube 25 of heat-resisting material, such as silica, which is preliminarily raised to a temperature within the muffle 27 by means of gas burners 28. The pinion 11 is held within the coil 12 until its temperature reaches that desired and is



then immediately dropped into the tank 24 containing a quenching liquid. The use of a high frequency current in the coil 12 develops the heat at substantially the surface only of the pinion 11 and permits heat treatment of the surface without materially affecting the structure of the interior of the pinion.

1,688,438, Oct. 23, 1928, Making Malleable-Iron Castings, Harry A. Schwartz, Cleveland Heights, Ohio, Assignor to National Malleable and Steel Castings Company, of Cleveland, Ohio, a corporation of Ohio.

This patent relates to a method of accelerating the annealing or malleableizing cycle of malleable cast iron which comprises taking iron castings of the normal malleable composition from the mold at a temperature above their critical point, cooling the iron rapidly from this temperature to a temperature below the critical point and subjecting the casting to an annealing cycle, which comprises reheating to a temperature above the critical point and holding it at this temperature for a sufficient time to break down the cementite and then cooling to below the critical point. The time of reheating necessary to destroy the cementite is approximately three to ten hours.

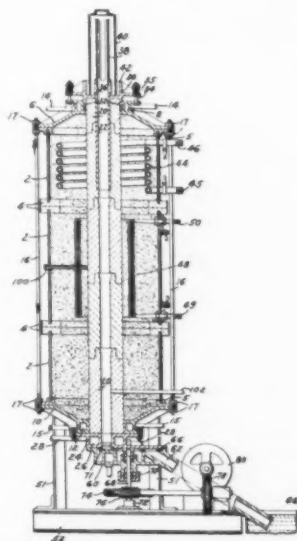
1,691,207, Nov. 13, 1928, Process of Refining Metals and Alloys, Aladar Pacz, of East Cleveland, Ohio.

This patent describes a method of deoxidizing molten materials which have a great avidity for oxygen, such as metallic silver or copper, or mixtures of the two, so as to provide a casting which is free from bubbles, blow holes or oxidization and of a density superior to that obtained by other modes of casting. The method comprises the use of a deoxidizing agent which pro-

duces the beneficial results desired without any injurious effect whatsoever on the metals, and consists of the addition of an alkali compound, such as sodium fluoride, to the molten metal, which compound dissociates under the conditions of the operation with the liberation of an alkali metal and gas. The alkali metal combines with the nonmetallie impurities in the bath to produce a very fusible and limpid slag while the gas is freely evolved from the bath. In addition to sodium fluoride, other alkali fluorides may be used, as well as other deoxidizing substances.

1,691,349, Nov. 13, 1928, **High-Frequency Induction Furnace**, George F. Harrington, of Edgewood, and Porter H. Brace, of Wilkinsburg, Pennsylvania, Assignor to Westinghouse Electric and Manufacturing Company, a corporation of Pennsylvania.

This patent describes a high frequency induction furnace consisting of the graphite tube or muffle 20, into which articles, such as disks to be heat



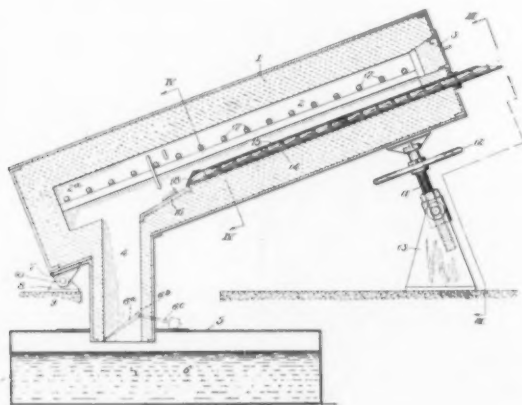
treated, are stacked and passed downward through the preheating coil 44, which is water cooled by the connections 45 and 46, and through the heating coil 48 which is likewise water cooled. The furnace is provided with an annular shell 2 of refractory material and the space between the shell 2 and the graphite tube 20 is packed with suitable insulating material, such as zirconium silicate. The disk-shaped articles stacked in the muffle 20 are removed one by one by means of a rotating plate 66 having openings for receiving the disk and operated from the motor 80 by means of the reduction gearing 78, 76 and 74, and the shaft 68. As the rotating plate 66 rotates below the disks stacked in the muffle 20, the holes in the plate receive the disks on the bottom of the stack and move them around to the discharge chute 62 from which they can be dropped into the quenching bath 64, and as the plate 66 rotates continuously, the bottom disks in the heating muffle are removed intermittently to permit lowering of the stacked disks through the preliminary heat and heat treating zone.

1,692,532, Nov. 20, 1928, Wash or Coating for Ingot Molds, John W. Alden, of Canton, Ohio, Assignor to Central Alloy Steel Corporation, of New York, N. Y., a corporation of New York.

This patent describes a wash or coating for ingot molds comprising a mixture of commercial aluminum powder and tar together with a suitable binder which may be applied to the interior of the molds when they are of a sufficient temperature to dry out the moisture. During casting, the aluminum provides a repellent action to splashes of steel against the mold wall and has a deoxidizing effect upon the surface of the steel while the tar produces a slight smoke as the level of the steel rises in the mold, forming a layer of carbon or soot upon the sides of the mold which assists in repelling splashes or waves of the molten steel.

1,692,614, Nov. 20, 1928, Heating Furnace, Richard E. Bissell, of Cleveland Heights, Ohio, Assignor to Thompson Products, Incorporated, of Cleveland, Ohio, a corporation of Ohio.

This patent describes a heating furnace consisting of a muffle 1, heated by means of electric resistance elements 17 and mounted on a trunnion 10



so as to permit tilting thereof by means of the screw 11 and hand-wheel 12. The articles to be treated, such as the poppet valves, are fed into the tubes 15 of the furnace, which is tilted to substantially the angle of repose of the articles so that little effort is necessary to push them through and, on reaching the ends of the tubes 15, the articles pass beneath the door 18 and are discharged across the plate 16 through the pivoted door 6a into the quenching bath. 6.

1,693,923, Dec. 4, 1928, Coating for Molds, Arthur J. Hess, of Detroit, Michigan, Assignor to Earl Holley, of Detroit, Michigan.

This patent describes a wash for cooling metal molds adapted for use in the production of iron castings. The wash consists of a mixture of two parts of a suspension of graphite and silica in kerosene mixed with one part of a dilute solution of sodium silicate in water. The wash provides a smooth coating which is later covered with a coating of lamp-black to protect the mold and the casting.

THE ENGINEERING INDEX

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Arrangements have been made with The American Society of Mechanical Engineers whereby the American Society for Steel Treating will be furnished each week with a specially prepared section of The Engineering Index Service. It is to include items descriptive of articles appearing in the current issues of the world's engineering and scientific press of particular interest to members of the American Society for Steel Treating. These items will be selected from the Weekly Card Index Service of the Index published by the A. S. M. E.

In the preparation of the Index by the staff of the A. S. M. E. some 1,700 domestic and foreign technical publications received by the Engineering Societies Library (New York) are regularly searched for articles giving the results of the world's most recent engineering and scientific research, thought, and experience. From this wealth of material the A. S. S. T. will be supplied with a selective index to those articles which deal particularly with steel treating and related subjects.

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AIRCRAFT ENGINES

MANUFACTURE—METALS. Metallurgy and the Aircraft Engine, H. Fishbeck. *Heat Treating and Forging*, vol. 14, no. 9, Sept. 1928, pp. 1023-25, 6 figs.

Function of metallurgical laboratory in operations of modern aircraft company; highest standards for materials and treatments are set by aeronautical engineer; aluminum alloy, some steel, and little bronze make up motor; material specification; largest aluminum forging made is used in Pratt Whitney crankcase; raw-material inspection; heat treatment.

AIRPLANES

MANUFACTURE—HEAT TREATMENT. Heat Treating Parts for Airplane Manufacture, J. B. Nealey. *Iron Trade Rev.*, vol. 83, no. 15, Oct. 11, 1928, pp. 899-900 and 902, 3 figs.

Heat-Treating Methods in plant of Mono-Aircraft Co., Moline, Ill., in manufacture of airplanes and engines; kind of heat treating adopted for duralumin fittings; procedure for gears and other parts made from forgings; maximum physical properties developed by heat treating in order to reduce weight; heat treating landing gear axle.

MATERIALS. Airplane Construction, Steel vs. Duralumin (La construction des avions), L. Merlin. *Metallurgie et la Construction Mecanique (Paris)*, no. 44, Nov. 1, 1928, pp. 5 and 7.

Discussion of strength of steel, duralumin, and wood when used in airplanes and advantages of each; examples of plane constructions of steel and duralumin; future.

ALLOYS

HEAT RESISTING. Heat-Resistant Alloys.

Am. Mach., vol. 69, no. 14, Oct. 4, 1928, p. 551.

Composition, properties, and applications of certain heat-resisting alloys are discussed, and include Atha's 2600 alloy, nichrome, ascology, and Delhi rustless iron; heat-resistant alloys are in general based on nickel and chromium, but may contain amounts of iron up to 60 per cent or more.

HEAT RESISTING. Heat Resisting Alloys, T. H. Turner. *Am. Metal Market*, vol. 35, no. 179, Sept. 18, 1928, pp. 12-14, 4 figs.

Heat-resisting alloys used in connection with electricity; in internal-combustion engines, in guns and rifles for hot forging dies, and in chemical industries. Paper read before Inst. of Metals.

IMPROVEMENT. The Improvement of Alloys and Newly Discovered Aging Phenomena in Iron (Verguetbarkeit von Legierungen und neuartige Alterungserscheinungen beim Eisen), G. Masing. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 2, no. 3, Sept. 1928, pp. 185-194, and discussion 195-196, 23 figs.

Effect of different heat treatments on properties of duralumin; theory of critical dispersion and its difficulties; investigations of beryllium-copper alloys; possibilities of improving iron-carbon alloys.

MAGNETIC—PERMINVAR. The Perminvars, a Group of New Magnetic Alloys, G. W. Elmen. *Bell Laboratories Rec.*, vol. 7, no. 1, Sept. 1928, pp. 1-4, 3 figs.

Specially suited for magnetic uses in electric communication circuits; perminvar properties are developed by heat treatment; measurements for composition 45 per cent nickel, 25 per cent cobalt, and 30 per cent iron, specially heat treated, are plotted in figures.

Those members who are making a practice of clipping items for filing in their own filing system may obtain extra copies of the Engineering Index pages gratis by addressing their request to the society headquarters, whereby their names will be placed on a mailing list to receive extra copies regularly.

ALLOY STEELS

AUTOMOTIVE. Alloy Steels and Their Application in the Automotive Industry, B. Egeberg. *Soc. Automotive Engrs.—Jl.*, vol. 23, no. 4, Oct. 1928, pp. 362-369 and (discussion) 370, 1 fig.

Progress of research in development of alloy steels; alloys of steel with nickel, with chromium, and with both nickel and chromium, are most important to automotive industry; detailed discussion of so-called high-carbon Krupp type of steel; consideration must be given to corrosive agents with which alloy steel will come into contact; mechanism of corrosion.

CUTTING QUALITIES. Cutting Qualities of an Alloy Steel As Influenced by Its Heat Treatment, O. W. Boston and M. N. Landis. *Am. Soc. Steel Treating—Preprint*, No. 7, for mtg. Oct. 8-12, 1928, 18 pp., 35 figs.

Estimating machinability rating of S.A.E. 6140 steel under various heat treatments; cutting rating as influenced by tool life and finish secured; torque and thrust of $\frac{3}{4}$ -in. drill as measured on drill dynamometer; time of $\frac{3}{4}$ -in. drill to penetrate $\frac{3}{4}$ in.; pure annealing does not give best machining qualities; steels cut best when spheroidizing is greatest. See abstract in *Am. Mach.*, vol. 69, no. 16, pp. 624-625.

HEAT RESISTING. The Properties of Materials for Use at High Temperature, with Special Reference to Boilers for Superheated Steam, R. G. C. Batson. *Instn. Civil Engrs.—Introductory Notes (Lond.)*, group 2, 1928, pp. 12-16.

Results expected from steels used for boiler and superheated tubes, and superheater and steam drums given in tables; possible to obtain materials that will meet requirements for increased steam pressures and temperatures; involve use of expensive alloys.

PROPERTIES. Examination and Properties of Special Steels (Pruefung und Eigenschaften von Staehlen mit physikalischen Besonderheiten), F. Staebelin. *Zeit. fuer technische Physik (Leipzig)*, vol. 9, no. 4, 1928, pp. 145-147, 5 figs.

Examples are given of iron alloys showing special magnetic behavior; thermal expansion of nickel steels is considered, and effects of temperature and addition of other elements on specific resistance of iron are summarized.

VOLUMETRIC DETERMINATION. Ceric Sulfate as a Volumetric Oxidizing Agent, H. H. Willard and P. Young. *Indus. and Eng. Chem.*, vol. 20, no. 9, Sept. 1928, pp. 972-974, 2 figs.

Oxidation of vanadylion by ceric sulphate in presence of chromic salts, ferric salts, and tungstic acid is selective in hot sulphuric acid solution; also, reduction of ceric ion by ferrous sulphate in presence of canadic acid is selective at room temperature; analysis of chrome-vanadium and chrome-vanadium-tungsten steels show that this method of determining vanadium is accurate one.

ALUMINUM

WELDING. Aluminum Welding an Aid to Aviation, D. M. Gershon. *Welding Engr.*, vol. 13, no. 9, Sept. 1928, pp. 39-40, 6 figs.

Ideal of lightness and strength of material and soundness of joint is achieved in welded aluminum construction; in construction of

these parts, oxyacetylene-welding process is employed.

ALUMINUM ALLOYS

The Light Alloys (Les alliages légers), F. C. Haus. *Service Technique de l'Aéronautique—Bul. (Brussels)*, no. 8, June 1928, pp. 13-30, 4 figs.

Classification; heat treatment; aluminum-copper structural alloy; duralumin; acceptance tests to be made in shops; threading.

AIRCRAFT. Aircraft Casting Alloys Must Possess Stability and Permanence, A. J. Lyon. *Foundry*, vol. 56, no. 21, Nov. 1, 1928, pp. 875-879, 5 figs.

Results of study made by Material Division, Air Corps, of physical properties in several aluminum alloys are discussed; even though some alloys have good properties directly after casting or heat treatment, they are not satisfactory for stressed parts; aging effects; alloy containing 2.5 per cent copper and 0.5 per cent magnesium is high-strength alloy; aluminum-zinc alloys. Abstract of paper presented before Metals Division, Am. Inst. Min. and Met. Engrs.

ELASTIC LIMIT. The Elastic Limit and Figure of Merit of Light Alloys (Guetezahlen und Elastizitaetsgrenzen bei Leichtmetallen), A. Schroeder. *Zeit. fuer Flugtechnik u. Motorluftschiffahrt (Munich)*, vol. 19, no. 5, Mar. 14, 1928, pp. 105-106.

Custom of comparing performance of light alloys on basis of saving in weight for same tensile strength is fallacious, since no consideration for safety is given; what is required is not comparison of ultimate tensile but infinite life under reversal of stress; point is closely related with elastic limit of material; elastic limit has to be determined with great accuracy in order to render comparison of value.

PROPERTIES. Aluminum Alloys (Ueber Aluminium-Legierungen), A. Merz. *Giesserei (Duesseldorf)*, vol. 15, no. 34, Aug. 24, 1928, pp. 836-840, 3 figs.

Properties and improvement of best known aluminum alloys are discussed, including duralumin, aldur, skleron, aeron, konstruktal, montegal, lantal, silumin, alneon and neonalium.

ALUMINUM ALLOY CASTINGS

Aluminum Alloys and Castings. *Automobile Engr. (Lond.)*, vol. 18, no. 245, Sept. 1928, pp. 340-341.

Disadvantages of sand castings and methods of overcoming some of them; principal advantages of gravity and pressure die-casting methods; in production gravity casting process used for suitable parts frequently works out cheaper than sand castings and sometimes even cheaper than pressure castings, since very expensive equipment required for pressure casting is unnecessary.

New Aluminum Alloys of High Elastic Limit Which Improve with Age (Neue selbstveredelnde Aluminium-Gusslegierungen mit hoher Elastizitaetsgrenze), M. v. Schwarz. *Zeit. fuer Flugtechnik und Motorluftschiffahrt (Muenchen)*, vol. 19, no. 16, Aug. 28, 1928, pp. 361-364, 18 figs.

Properties of alneon and neonalium aluminum castings, their use in manufacture of aircraft engines, machine tools, pianos, etc.; remarkable spontaneous increase in hardness within first 10 days after casting.

Silicon-Aluminum Castings (Silizium-Aluminium-Gusslegierungen), J. Dornauf. *Zeit. fuer Metallkunde (Berlin)*, vol. 20, no. 8, Aug. 1928, pp. 289-292, 14 figs.

Author discusses influence of silicon, iron, magnesium, manganese, copper, zinc, tin and antimony on silumin; frequency curves of sand cast silumin with regard to tensile strength and elongation.

The Production of Non-Porous Castings of Aluminum Alloys (Zur Kenntnis der Erzeugung gasporenfreier, dichter Gussstuecke aus Aluminium-Legierungen), W. Claus and E. Kalachne. *Giesserei (Duesseldorf)*, vol. 15, no. 40, Oct. 5, 1928, pp. 996-1000, 12 figs.

Discussion of cause of gas porosity; results of tests with "Y"-alloy (1.5 per cent magnesium, 2 per cent nickel, 4 per cent copper, 92.5 aluminum); tests were also carried out on so-called "American" alloy (copper 8 per cent, aluminum 92 per cent).

TESTING. Stability of Aluminum and Magnesium Casting Alloys, A. J. Lyon. *Am. Inst. Min. and Met. Engrs.—Tech. Publication*, no. 133, Sept. 1928, 15 pp., 5 figs.

Test specimens cast in green sand and ordinary foundry practice observed; chemical composition determined on original melts; aluminum-copper alloys; aluminum-copper-magnesium; aluminum-copper-nickel-magnesium; aluminum-silicon; aluminum-zinc; magnesium-aluminum-manganese; magnesium-zinc-aluminum.

ALUMINUM BRASS

Aluminum Brasses, E. R. Thews. *Can. Chem. and Met. (Toronto)*, vol. 12, no. 9, Sept. 1928, pp. 246-248.

Discussion of metallurgical properties which have a bearing on difficulties met with frequently in manufacturing practice; aluminum and hot rolling of brass; metallurgical considerations; applications of aluminum brasses.

AUTOMOBILES

GEARS AND GEARING—MANUFACTURE. New Forging Method Improves Grain of Ring Gear Blanks, A. F. Denham. *Automotive Industries*, vol. 59, no. 14, Oct. 5, 1928, pp. 472-474, 6 figs.

Dodge practice of upsetting bar stock gives uniform grain structure which makes for better machining and wearing qualities and lessens distortion from heat treating; scrap reduced to minimum.

TRANSMISSIONS -- HEAT TREATMENT. Precision Heat Treatment for Gears. *Iron Age*, vol. 122, no. 13, Sept. 27, 1928, pp. 761-764, 4 figs.

Heat-treating operations on automobile transmission and ring gears at plant of Dodge Bros.; six-zone annealing, controlled to 7 deg., necessary for maximum machinability; oil for quenching presses held to 3 deg., plus or minus.

BODIES, STEEL. Sheet Steel for Automobile Bodies. *Blast Furnace and Steel Plant*, vol. 16, no. 10, Oct. 1928, pp. 1313-1318, 14 figs.

Common surface defects which impair or destroy usefulness of sheets are described and illustrated; causes of faulty surface are discussed and remedies outlined; roller leveling and oiling; open-hearth defects; defects arising in mills; hot-mill pinchers; polishing scratches; hot-mill grease; normalizing pits;

pickling patches and wood pits; annealing oxide and open surface.

BODIES, STEEL. Sheet Steel for Automobile Bodies. *Heat Treating and Forging*, vol. 14, no. 10, Oct. 1928, pp. 1166-1170, 9 figs.

Most rapid and accurate tests for sheet steel are found in Erickson or Olsen ductility testers and Rockwell for hardness; these tests are sufficient if only to maintain "spot checks" on general run of steel, but for closer check, microscopical examination for uniformity of grain and presence of structural defects is necessary; tensile strength data likewise dependent on structural examination.

BEARING METALS

TIN BASE. A Study of Tin-Base Bearing Metals, O. W. Ellis and G. B. Karelitz. *Machine-Shop Practice (A.S.M.E. Trans.)*, vol. 50, no. 18, May-Aug. 1928, pp. 13-27 and (discussion) 27-28, 64 figs.

First part of investigation of babbitts; results of metallographic and mechanical tests on series of tin-antimony-copper alloys containing up to 10 per cent of antimony and 8 per cent of copper; relationships between composition, microstructure, hardness, and compressive strength of these alloys; influences of elevated temperatures and of lead upon these properties.

BRASS FOUNDRY PRACTICE

The Fundamentals of Brass Foundry Practice, R. R. Clarke. *Metal Industry (N. Y.)*, vol. 26, no. 9, Sept. 1928, pp. 390-391, 3 figs.

Description of basic laws which control melting and casting of metals and their application to practical foundry work.

CADMIUM PLATING

CADMIUM PLATING. *Indian Eng. (Calcutta)*, vol. 84, no. 10, Sept. 8, 1928, pp. 137-138.

Good cadmium plating is one of best rust preventatives known; simplicity of plating process itself; corrosion of cadmium is slower than that of zinc; cadmium is deposited for given current, more rapidly than copper, zinc or nickel.

Cadmium and Nickel Plating of Small Parts, F. W. Curtis. *Am. Mach.*, vol. 69, no. 11, Sept. 13, 1928, pp. 437-440, 8 figs.

Operating equipment and methods used in plant of Bassick Mfg. Co., Chicago, in plating screw-machine products and metal stampings of steel and brass, are described; most of work performed automatically.

CASE HARDENING

Depth and Character of Case Induced by Mixtures of Ferro-Alloys With Carburizing Compounds, E. G. Mahin and R. C. Spencer. *Am. Soc. Steel Treating—Advance Paper for mtg.*, Oct. 8-12, 1928, 26 pp., 14 figs.

Experiments show that if silicon absorption is confined to surface layers of iron or steel, carbon absorption during case carburization may be retarded without materially affecting rate of inward migration of carbon after it has been absorbed; deep case produced without zone of free cementite, by using ordinary carburizer in conjunction with ferrosilicon and by employing higher carburizing temperatures, thus shortening time required.

AMMONIUM FORMATE. Steel Hardening with Formate Salts (Verstaehtung mittels ameisensauren Salze), H. Reininger. *Maschinenbau (Berlin)* vol. 7, no. 18, Sept. 20, 1928, pp. 871-875, 8 figs.

Merits of ammonium formate as hardening or steeling agent; ferrous alloys which can be hardened, treatment following hardening microstructure of hardened layers; uses of "steeling" process for hardening of machine parts, etc.; author uses word, Verstaehtung ("steeling") instead of cementation, as he claims latter expresses only action of carbon, but not that of nitrogen.

CARBURIZING. On the Energizing Action of Carbonates Contained in Carburizing Mixture, G. Takahashi. *Tohoku Imperial Univ.—Science Reports (Sendai, Japan)*, vol. 17, no. 5, Aug. 1928, pp. 883-926, 28 figs.

Velocity of carburization in iron and steel is much more accelerated by use of carburizing agent which consists of mixture of some carbonate and carbon, than in case where carbon alone is used; shows that carburization is due to action of carbonate which sets free carbon from carbon monoxide, nascent carbon atoms diffusing very easily into iron and iron and steel. (In English.)

CYANIDE FLUX. A Cyanide Flux for Case-hardening. *Engineering (Lond.)*, vol. 126, no. 3274, Oct. 12, 1928, p. 471.

Description of hardening medium, consisting of sodium cyanide together with various ingredients which act as accelerators, placed on market under name of Duferrit cyanide hardening flux; it is claimed that carburization to depth of 0.4 mm. can be secured by immersing mild steel in bath of molten flux, at temperature of 950 deg. cent., for ½ hr.; flux is supplied in shape of balls, each weighing a few ounces.

NITRATION. Recent Developments in the Application of Nitrogen to the Surface Hardening of Steel, V. O. Homerberg. *Fuels and Furnaces*, vol. 6, no. 9, Sept. 1928, pp. 1153-1157, 9 figs.

New series of steels containing aluminum has been evolved which are discussed and method of nitriding is described; nitriding period; uses of nitrided aluminum-alloy steel.

NITRATION. Nitralloy—A New Steel, L. Buillet. *Am. Metal Market*, vol. 35, no. 19, Sept. 1928, pp. 7 and 10.

Steels for nitriding are now being manufactured in United States; manufacturing process employed summarized; nitriding certain special steels permits some entirely new and interesting solutions to problems from point of view of weight, cost and life of parts. Translation of paper read before Paris Academy of Sciences.

NITRATION. The Process of Surface Hardening of Steel by Nitriding, W. J. Merten. *Fuels and Furnaces*, vol. 6, no. 10, Oct. 1928, pp. 1371-1376, 4 figs.

Detailed description of nitriding process and equipment required; preparation of steel for nitriding; operation of nitriding equipment; control of time, temperature and depth of case; selective nitriding; quenching and tempering.

NITRATION. Methods of Approximating Certain Physical Characteristics of Nitrided Steel Cases, G. M. Eaton. *Am. Soc. Steel Treating—Preprint*, no. 9, for mtg., Oct. 8-12, 1928, 24 pp., 18 figs.

Need for inspection testing of nitrided

products; vital characteristics of case are hardness and ductility; impressions produced on nitrided case by practically all recognized hardness-testing machines shown by photomicrographs and discussed; Vickers diamond indenter hardness tester gives clearest distinction between brittle and ductile characteristics of nitrided cases. See abstract in *Am. Mach.*, vol. 69, no. 16, p. 627.

NITRATION. Surfacing Hardening of Special Steels With Ammonia Gas Under Pressure, R. H. Hobrock. *Am. Soc. Steel Treating—Preprint*, No. 4, for mtg., Oct. 8-12, 1928, 16 pp., 12 figs.

Samples of special steels nitrided with ammonia gas under pressure and nature of case so produced examined; increase in pressure of ammonia gas results in decrease in surface hardness, but greatly increases depth of case produced in given time; correction of hardness, time of treatment and depth of case shown by curves; explanation of phenomena observed proposed. See abstract in *Am. Mach.*, vol. 69, no. 16, p. 625.

NITRATION. Nitrogen Process for Surface Hardening. *Metallurgist (Supp. to Engineer, Lond.)*, Oct. 26, 1928, pp. 154-155, 1 fig.

Advantages claimed over case-hardening are listed; certain precautions necessary to obtain best results are cited; investigations indicate that steels subjected to nitrogen hardening process possess considerable resistance to corrosive action of steam, water, and various atmospheres, and show well-marked superiority over case-hardened plain or alloy steels in this respect; analyses and treatment of steels are shown in table.

NITRATION. Some Practical Aspects of the Nitriding Process, H. W. McQuaid and W. J. Ketcham. *Am. Soc. Steel Treating—Trans.*, vol. 14, no. 5, Nov. 1928, pp. 719-743, 24 figs.

Paper discusses nitriding process from practical viewpoint and touches upon usual method, referring to patents of Machlet and Fry; advantages and disadvantages of process; Vickers method indicating hardness of test pieces at different depths; for general nitriding purposes, 1200 deg. Fahr. is recommended; commercial application of process.

CASTING

CENTRIFUGAL. Improvements in Molds for Making Hollow Cylindrical Castings Whose Diameter is Small with Respect to the Length, by Centrifugal Force (Perfectionnements apportés aux moules pour la fabrication, par la force centrifuge, de corps creux cylindriques dont le diamètre est petit par rapport à la longueur). *Fonderie Moderne (Paris)*, vol. 22, Mar. 25, 1928, pp. 106-108, 6 figs.

Describes new type of mold for centrifugal casting in which delivery spout is supported by single ball resting on inner surface of rotating mold.

CAST IRON

COMPOSITION. Constitution of Cast Iron. *Iron and Steel Industry (Lond.)*, vol. 1, no. 12, Sept. 1928, pp. 368-370 and 386, 1 fig.

Constitutional diagram of cast iron is described and its practical bearing on nature, strength, and application of cast iron is discussed; functions of carbon, silicon, manganese, sulphur, and phosphorus; mixing of

cast iron and influence of constituents on its properties.

GROWTH. Growth of Cast Iron, E. Morgan. *Metallurgist (Suppl. to Engineer, Lond.)*, Aug. 31, 1928, pp. 120-121.

Review of paper published in Brit. Cast Iron Research Assn.—Bul., Apr. 1928.

HARDNESS TESTING. Hardness Testing Cast Iron, H. Pinsl. *Foundry Trade J. (Lond.)*, vol. 39, no. 632, Sept. 27, 1928, p. 228, 1 fig.

Although Brinell hardness is most common, method is not applicable when piece to be tested is large and one cannot be put on platform of Brinell machine; author examined relationship between Brinell method, Shore scleroscope method, and Poldi method to find out whether it might be possible to convert test values obtained by them into Brinell hardness numbers. Translated from Gieserei-Zeit., 1928.

CHROMIUM PLATING

The Many Manufacturing Uses of Chromium Plating, W. M. Phillips. *Factory and Indus. Mgmt.*, vol. 76, no. 3, Sept. 1928, pp. 484-488, 6 figs.

Among many products now plated with chromium are dies for stamping and drawing metals, wire-drawing dies, copper rolls for printing paper, locomotive-control devices, cutlery, jewelry, golf clubs; these and other applications are described and advantages are shown.

Chromium Plating—A New Tool in Industry, O. P. Watts. *Wisconsin Engr.*, vol. 32, no. 8, May 1928, pp. 256, 284 and 286.

Author has done considerable research work on development of chromium plating; peculiar action of chromium when being deposited electrolytically necessitated much experimentation before successful commercial application was possible; properties of chromium plate; chromium plate provides surface which has low coefficient of friction and to which other metals do not stick; it resists heat and oxidation remarkably.

CHROMIUM STEEL

CORROSION TESTING. Electrochemical Behavior and Corrosive Properties of Chromium Steels (Elektrochemisches Verhalten und Rostneigung von Chromstaehlen), O. Meyer and K. Roesch. *Stahl und Eisen (Duesseldorf)*, vol. 48, no. 39, Sept. 27, 1928, pp. 1372-1373.

Abstract of report No. 130, previously indexed from Archiv fuer das Eisenhuettenwesen (Duesseldorf,) Aug. 1928.

FLAKES. Flakes in Chromium Steel (Flocken im Chromstahl), W. Aichholzer. *Stahl und Eisen (Duesseldorf)*, vol. 48, no. 38, Sept. 20, 1928, pp. 1332-1334, including discussion, 2 figs.

Results of investigation on steels containing 0.8 to 1.2 per cent and 1 to 3 per cent chromium; manganese and silicon content fluctuated between 0.2 and 0.3 per cent. Abstract of report No. 105 of Materials Committee of Verein deutscher Eisenhuettenleute.

CHROMIUM-ALUMINUM STEEL

PROPERTIES. An Investigation of the Physical Properties of Certain Chromium-Aluminum Steels, F. B. Lounsbury and W. R. Breeler. *Am. Soc. Steel Treating—Advance*

Paper, no. 23, for mtg., Oct. 8-12, 1928, 31 pp., 13 figs.

Physical properties investigated for steel containing as main alloying constituents, aluminum and chromium with silicon and carbon; aluminum effectively stabilized alpha-iron phase and when in combination with chromium, greatly increased resistance of metal to oxidation at elevated temperatures; addition of nickel produced unusual low temperature phenomenon.

CHROMIUM-COPPER STEEL

ANTI-CORROSIVE. Chromium-Copper Steels As Possible Corrosion Resisting Ferrous Alloys, B. D. Saklatwalla and A. W. Demmler. *Am. Soc. Steel Treating—Advance Paper*, no. 28, for mtg., Oct. 8-12, 1928, 15 pp., 17 figs.

Results of experimental laboratory work in study of merits of chromium-copper combination in steel; purpose was development of commercial steels of high physical properties combined with fair corrosion resistance and producible at commercially reasonable cost.

CHROMIUM-NICKEL STEEL

The Scope of Corrosion-Resisting Steels in Chemical Engineering, T. H. Burnham. *Indus. Chemist (Lond.)*, vol. 4, no. 43, Aug. 1928, pp. 320-324, 9 figs.

Range of alloy steels concerned covers from 10 to 30 per cent of chromium and 7 to 40 per cent of nickel, with iron content of from 50 to 70 per cent; discusses application in which corrosion-resisting steels have established their industrial utility and consideration of physical and mechanical properties of these materials.

CORROSION. Tests on Acid Resistance of Pure Chromium-Nickel-Iron Alloys (Einige Versuche ueber Saeurebestaendigkeit reinster Chrom-Nickel-Eisenlegierungen), W. Guertler and W. Ackermann. *Zeit. fuer Metallkunde (Berlin)*, vol. 20, no. 8, Aug. 1928, pp. 269-279, 17 figs.

Author investigates corrosive effect of chemical agents, especially acids, on nickel-iron, chromium-iron, and chromium-nickel-iron alloys; discusses behavior of these alloys in presence of different acids and of artificial seawater. Bibliography.

COPPER

DEFECTS. Defects in Fabricated Copper, Roemer. *Metal Industry (N. Y.)*, vol. 26, no. 9, Sept. 1928, pp. 386-387.

Effect of hydrogen on copper when oxygen is present as oxide; effects of iron, carbon monoxide, and sulphur on copper. Translation of article published in Oct. 25, 1927, issue of Metallwirtschaft.

SHEET, ELECTROLYTIC. Debex Process of Manufacturing Sheets of Electrolytic Copper (La fabrication des planches de cuivre electrolytique Debex). *Bul. Technique de la Suisse Romande (Paris)*, vol. 54, no. 16, Aug. 11, 1928, pp. 189-191, 4 figs.

Describes deposition of copper on cylinders by electrolytic means, how it is removed and uses for it in roofing work; physical characteristics of these sheets.

COPPER ALLOYS

SPECIFICATIONS. A. S. T. M. Proposed Tentative Specification. *Am. Metal Market*,

vol. 35, no. 179, Sept. 18, 1928, pp. 15-16, 2 figs.

For sand castings of alloys; copper 80 per cent, tin 10 per cent, lead 10 per cent; chemical and physical properties; tests; workmanship and finish.

COPPER ALLOY CASTINGS

PROPERTIES. The Tensile Properties of Some Sand-Cast Copper Alloys, R. J. Anderson. *Am. Metal Market*, vol. 35, no. 19, Sept. 1928, pp. 11 and 16, 3 figs.

Tensile and hardness tests were made of seven alloys which were not heat treated; results of these heat tests are given; method of casting and testing; tensile properties and uses.

CORROSION PREVENTION

ELECTROCHEMICAL. The Struggle Against Corrosion Through Electrochemical Treatments (La lutte contre la corrosion par les traitements électrochimiques), Cournot. *Société Française des Electriciens—Bul. (Paris)*, vol. 8, no. 83, July 1928, pp. 692-706.

Importance of corrosion problem; theories of corrosion; methods of protection by electric current; electrochemical protection and electrolytic deposits; cobalt, cadmium, and chromium plating.

CUPOLAS

DESIGN. Special Types of Cupolas (Sonderbauformen und Sonderbetriebsformen des Kupolofens), L. Schmid. *Giesserei (Duesseldorf)*, vol. 15, no. 32, Aug. 10, 1928, pp. 781-792, 10 figs.

Notes on oxidation or combustion zone; substitution of liquid or pulverized fuels for coke; reduction of carbon-monoxide formation; combustion of carbon monoxide by secondary air; heating of blast; enrichment of cast iron with silicon, manganese and phosphorus; desulphurization of cast iron; production of high-cast iron.

POUMAY. The Poumay Cupolas (Der Kupolofen nach Poumay), C. Geiger. *Gesere (Duesseldorf)*, vol. 15, no. 33, Aug. 17, 1928, pp. 816-819, 1 fig.

Author discusses peculiarities in design and operation of Poumay cupola; operating results and analysis of reasons for success.

DIE CASTING

DIE CASTING. *Metallurgist (Supp. to Engr., Lond.)*, Sept. 28, 1928, p. 129.

Brief comment on papers and discussion on die casting at last meeting of Institute of Metals; although papers gave records of laboratory results, discussion was carried on by practical men, dealing with practical problems; discussion seems to be mainly useful in pointing out need for much further investigation.

COPPER ALLOYS. Die-Casting of Copper-Rich Alloys, R. Genders, C. R. Reader and V. T. S. Foster. *Foundry Trade J. (Lond.)*, vol. 39, no. 629, Sept. 6, 1928, pp. 167-170 and 172.

Investigation summarized in paper, was undertaken with object of obtaining information regarding process of die casting high-melting-point alloys, material produced, and possibilities of improvement, ultimate aim being widening of scope of use for die casting; present methods of die casting; proper-

ties of selected alloys as chill-cast bars and as die castings; color and corrosion characteristics; results of tests. Abstract of paper read before Inst. of Metals, previously indexed.

DIE CASTING ALLOYS

British Discuss Die Casting Alloys. *Foundry*, vol. 56, no. 19, Oct. 1, 1928, p. 788.

Review of meeting of British Institute of Metals at Liverpool with brief abstract of papers; Die-Casting of Copper-Rich Alloys, R. Genders, R. C. Reader, and V. T. S. Foster; Properties and Production of Aluminum Alloy Die-Castings, S. L. Archbutt, J. D. Grogan, and J. W. Jenkin; Die-Casting Alloys of Low Melting Point, T. F. Russell, W. E. Goodrich, W. Cross, and N. P. Allen; Practical Pyrometry, G. B. Brook and H. J. Simcox.

DURALUMIN

HEAT TREATMENT. Heat Treatment of Duralumin, L. Aitchison. *Fuels and Furnaces*, vol. 6, no. 9, Sept. 1928, pp. 1191-1194.

To secure highest mechanical properties, duralumin is subjected to heat treatment, which consists in heating materials to critical temperature and then allowing metal to age at atmospheric temperature for four or five days; explains various heat treatments for obtaining improved properties in forged, rolled, and extruded duralumin.

ELECTRIC FURNACES

ANNEALING. Alloy Steel Castings Annealed in Car Type Electric Furnaces, M. Rock. *Fuels and Furnaces*, vol. 6, no. 10, Oct. 1928, pp. 1405-1407, 3 figs.

Describes two-car-type furnaces with accurately controlled heating and cooling cycles, used in heat treating great variety of steel castings; furnace cars are 6 ft. wide by 12 ft. long, with loading clearance of 4½ ft. from top of car to spring of arch; each heating chamber requires 375 kw., using T-Grid cast resistor element.

ANNEALING. Electric Normalizing and Annealing. *Iron Age*, vol. 122, no. 14, Oct. 4, 1928, pp. 818-821, 8 figs.

Description of bank of electric annealing installed by Timken Roller Bearing Co. for use in production of alloy steels; eight furnaces for slow cooling handle alloy steels at various heating cycles; large pit furnaces a feature; air blast for cooling; special furnace for normalizing chrome steel; two-car-type furnaces for bar stock.

ARC. Industrial Electric Heating, N. R. Stansel. *Am. Metal Market*, vol. 35, no. 198, Oct. 16, 1928, pp. 3-9 and 47, 18 figs.

Single-phase arc furnace is in wide use for melting in non-ferrous metal industry; diagram showing positions of rocking-type arc furnace during loading, melting, and pouring; relations between current, watts, and power factor in a.c. circuit made up of resistance and reactance; relation between arc length and watts in arc; standard sizes of single-phase arc furnaces for melting non-ferrous alloys; electric equipment of single-phase arc furnace.

ARC. Industrial Application of the Electric Furnace, H. H. Watson. *Tech. Eng. News*, vol. 9, no. 5, Oct. 1928, pp. 206-208, 216 and 224, 4 figs.

Performance of electric furnace as com-

pared with other metallurgical processes; discusses only arc-type furnace as applied to ferroalloys and steel, and manufacture of electric furnace in use today; direct arc, indirect arc, and induction; reasons for remarkable growth of electric furnace in iron and steel industry; production costs favorably comparable with cupola, converter, and open-hearth processes.

HEAT BALANCE. Energy Losses of a 7-Ton Héroult Furnace with Special Regard to Heat-Storage Phenomena (Energieverluste eines 7-t-Héroult Ofens unter besonderer Berücksichtigung der Waermespeicherungs-vorgänge), N. Wark. *Archiv fuer das Eisen-huettenwesen* (Duesseldorf), vol. 2, no. 3, Sept. 1928, pp. 145-150, 6 figs.

Results of heat-balance determination confirm in general, results of earlier investigations; it is shown that charging time, quality of scrap, and condition of refractory lining have great influence on heat losses of furnace; attempt is also made to explain flow of heat in lining of metallurgical furnace.

HEAT BALANCE. Energy Losses of a 15-Ton Héroult Furnace with Special Regard to Wear of Arch (Energieverluste eines 15-t-Héroult-Ofens unter besonderer Berücksichtigung der Gewoelbeabnutzung), H. Klinar, O. Huetteneisen (Duesseldorf), vol. 2, no. 3, Sept. 1928, pp. 151-153, 3 figs.

Results of investigations show decided influence of wear of furnace arch on heat losses; they confirm results of test on 7-ton Héroult furnace (see preceding article in same journal) with regard to heat-storage capacity of arch masonry; heat balances of charge molten in slag formation and in covering radiation losses.

INDUCTION. Coreless Induction Furnaces (Ueber eisenlose Induktionsoefen), C. R. Burch and N. R. Davis. *Archiv fuer Elektrotechnik* (Berlin), vol. 20, no. 3, July 1928, pp. 211-223, 7 figs.

Report from research laboratories of Metropolitan-Vickers Electrical Co. of Manchester, England; simplified theory of coreless induction furnace put to experimental test by study of performance of specially constructed furnace, capacity 45 kg. of brass, 50 cycles; results of test agree with theory and indicate good economic performance for 50-cycle furnace of 300 kg. capacity.

INDUSTRIAL. Industrial Electric Heating. N. R. Stansel. *Gen. Elec. Rev.*, vol. 31, no. 10, Oct. 1928, pp. 560-568, 12 figs.

Discusses Resistor, batch-type, and moving-charge furnaces; resistor furnaces classified; total loss of energy from resistor furnace; example not complicated by practical details used for illustration.

INDUSTRIAL. The Applications and Advantages of Electric Heat. J. L. Faden. *Indus. Power*, vol. 15, no. 4, Oct. 1928, pp. 147-151, 2 figs.

Application of electric heat-treating furnace; many advantages of electric heat; principal commercial applications; well adapted to heat treatment; space heaters serve well for small ovens.

RESISTANCE. The Use of Nickel-Chromium Alloys in Electric Furnaces, A. G. Lobley. *Foundry Trade JI. (Lond.)*, vol. 39, no. 631, Sept. 20, 1928, pp. 209-210, 2 figs.

Electric resistance furnaces are dependent on nickel-chromium alloys for their heating elements; early history of resistance furnaces; with 80-120 nickel-chromium alloy, furnace temperatures as high as 1100 deg. cent. have been recorded; devices for increasing electric load; advantages of electric furnace are exactness of control and flexibility.

FOUNDRY PRACTICE

Welding Facts and Figures. D. Richardson and E. W. Birch. *Welding JI. (Lond.)*, vol. 25, no. 299, Aug. 1928, pp. 238-240, 4 figs. Types of cupola furnaces in use; centrifugal casting; method of producing castings; essential principle of process is shown in diagrammatic form.

FURNACES

FORGING. Furnace Requirements for Mass Production, A. J. Stevenson. *Heat Treating and Forging*, vol. 14, no. 9, Sept. 1928, pp. 1061-1062, 5 figs.

Review of developments in furnace design; increase in output of automobiles has made necessary change in furnace construction to supply parts in sufficient quantity; continuous furnace; moving stock in furnace; furnaces for forging; division of zones in heat-treating furnaces.

FORGING. Tests of a Metal Recuperator Forge Furnace Heated With Blast-Furnace Gas (Essais d'un four de forge à récupérateurs métalliques chauffé au gaz de haut-fourneau), A. Lemonnier. *Chaleur et Industrie (Paris)*, vol. 9, no. 100, Aug. 1928, pp. 163-164.

Furnace characteristics; measuring apparatus; tests of heating steel pieces; temperature ranges; recuperators and their efficiency.

HEATING—ARCH INSULATION. Economy in Insulating Furnace Arches. *Heat Treating and Forging*, vol. 14, no. 10, Oct. 1928, pp. 1292 and 1206, 1 fig.

Survey by A. C. Nielsen Co., emphasizes fact that insulating brick effects saving in fuel of 19 per cent in gas-fired heating furnaces, due to reduction of heat losses through arch; gas consumption is less; working conditions about furnace no longer intolerable.

HEAT TREATING. Furnaces for Various Heat Treatments, P. C. Osterman and E. C. Cook. *Heat Treating and Forging*, vol. 14, no. 9, Sept. 1928, pp. 1066-1069 and 1086, 21 figs.

Many types of heating machines are described and illustrated, bringing out progress that has been made in mechanization of heating operations; means worked out for conveying work through heated space; early types of machines.

INDUSTRIAL—TESTING. Testing and Rating of Fuel Fired Industrial Furnaces, W. C. Buell, Jr. *Fuels and Furnaces*, vol. 6, no. 11, Nov. 1928, pp. 1505-1510, 4 figs.

Classification of tests, their uses and relative values; determination of heat balances; calculation of efficiency of furnace, heat-salvage apparatus, heat-generating apparatus; method developed is, with suitable modification, entirely practicable for use with any heating operation such as melting, refining or heating or reheating of solid substances such as metal; heating or reheating of steel only operation specifically covered.

METALLURGICAL—PULVERIZED COAL.

Heating of Metallurgical Furnaces by Pulverized Coal (Le chauffage au charbon pulvérisé des fours métallurgiques). *Technique Moderne (Paris)*, vol. 20, no. 20, Oct. 15, 1928, pp. 686-687 2 figs.

Description of application of pulverized coal to metallurgical furnaces; burners and combustion chambers are treated.

GEARS AND GEARING

HARDENING. The "Shorter" Gear Hardening Process. *Machy. Market (Lond.)*, no. 1458, Oct. 12, 1928, p. 940, 2 figs.

Outstanding feature of Shorter process is that instead of heating and hardening whole gear wheel, only that portion of tooth required to be hard is heated by oxyacetylene or other high-temperature flame, each tooth being immediately quenched in water as soon as necessary heat has been applied; machine is arranged to take gears of varying sizes.

HARDNESS TESTING INSTRUMENTS

PENDULUM. Test with Herbert Pendulum Hardness Tester (Versuche mit dem Herbert-Pendelhaertepreuer bei der Bearbeitung durch spanabhebende Werkzeuge). A. Wallich and K. Krekeler. *Stahl u. Eisen (Duesseldorf)*, vol. 48, no. 19, May 10, 1928, pp. 626-627, 4 figs.

Description of experiments of hardness changes carried out at Technische Hochschule at Aachen; materials tested were used in form of tubes of 4 mm. wall thickness; both case-hardening and heat-treated steels were tested; results after machining were not very conclusive. See translated abstract in *Metallurgist (Supp. to Engineer, Lond.)*, Sept. 28, 1928, p. 143.

HARDNESS TESTING MACHINES

Cloudburst Process for Hardness Testing and Hardening. E. G. Herbert. *Am. Soc. Steel Treating—Advance Paper*, no. 16, for mtg., Oct. 8-12, 1928, 16 pp., 15 figs.

Four functions of cloudburst process of bombardment with hard steel balls discussed; elimination of soft articles or articles having soft spots; measurement of hardness and its control between limits; superhardening of hard steel; production of work-hardened surface on steel, cast iron, and other metals; steel work-hardened surface can be further increased in hardness by annealing at temperature between 200 and 300 deg. Cent.

HARDNESS TESTS

BRINELL. On the Relation Between the Pressure and the Diameter of Impression in Hardness Test. K. Takahasi. *Tohoku Imperial Univ.—Sci. Reports (Sendai)*, vol. 17, no. 4, July 1928, pp. 843-856, 5 figs.

Meyer studied relation between pressure and diameter of indentation in Brinell test; writer studied relation for small pressures ranging from 5 to 100 kg. which were not examined by Meyer.

HIGH SPEED STEEL

HARDENING. Heating High Speed Steel to 2400 Degrees Fahr. in Molten Lead. W. C. Searle. *Am. Soc. Steel Treating—Advance Paper*, no. 29, mtg. Oct. 8-12, 1928, 4 pp., 3 figs.

Apparatus and method of heating high-speed steel to 2300 to 2400 deg. Fahr. in

molten lead are described; photomicrograph shows structure obtained in specimens at 2200, 2300, and 2400 deg. Fahr.; method of hardening is simple and very satisfactory for moderate production; little danger of destroying delicate edges before tool is heated through.

HARDENING. Effect of Hardening Temperatures and Annealing on Cutting Efficiency of High Speed Steels (Einfluss der Haertetemperatur und des Anlassens auf die Schnittleistung der Schnellarbeitstaehle). E. Kothny. *Maschinenbau (Berlin)*, vol. 7, no. 20, Oct. 18, 1928, pp. 959-966, 45 figs.

General review of properties of high-speed steels; comparative tests of cutting capacity of high-speed steels tempered at 350 and 590 deg. Cent. show advantages of higher temperature hardening.

HEAT TREATMENT. A New Method For Heat Treating High Speed Steel. H. C. Knerr. *Am. Soc. Steel Treating—Advance Paper*, no. 21, for mtg. Oct. 8-12, 1928, 17 pp., 7 figs.

Method described includes electric heating, close temperature control which may be made automatic, use of salt bath which does not give off fumes or attack tools, prolonged container life, absence of furnace deterioration, comfortable working conditions, low heating cost per pound of steel, and ability to employ full hardening temperatures without injury to finished surfaces or cutting edges of high-speed steel tools.

IMPACT TESTING

On the Determination of Stress and Strain during Impact Indentation. J. Okubo and M. Hara. *Franklin Inst.—Jl.*, vol. 206, no. 4, Oct., 1928, pp. 471-488, 10 figs.

Investigation is experimental work which was undertaken to ascertain phenomena relating to impact of two bodies; experimental arrangement; shutter; main pendulum; buffer system; rotating cylinder; experimental results and conclusions.

NOTCHED BAR. The Notched-Bar Impact Test [Ueber die Kerbschlagprobe (Schlagbiegeprobe)]. E. Honegger and M. Ros. *Schweiz. Verband fuer die Materialpruefungen der Technik, Bericht* no. 5, March, 1927, 63 pp., including discussion, 69 figs.

Theory of impact testing, general review of research work; description of Charpy, Izod, Amsler, and Guillery impact testing apparatus; examples from practice, microstructure of tested specimens.

NOTCHED BAR. A Standard Notched Bar Impact Test Piece. F. P. Fischer. *Metallurgist (Supp. to Engineer, Lond.)*, Aug. 31, 1928, pp. 123-124.

Author gives brief historical survey of impact testing and describes all better-known types of impact test pieces; his choice falls on Mesnager specimen, which has advantage that it is one of those specimens giving results which approach in magnitude those obtained from large Charpy test piece. Review of paper published in *Stahl u. Eisen*, Apr. 26, 1928, previously indexed.

INGOT MOLDS

SOLIDIFICATION. Solidification in the Mould. *Metallurgist (Supp. to Engineer, Lond.)*, Aug. 31, 1928, pp. 113-114.

Structure and properties of hot-poured metal are markedly different from those of same material cast into hot mold; whole phenom-

ena known as "inverse" or "negative" segregation have been much discussed in recent years, but no finally satisfactory explanation has yet been put forward; there are fatal objections to all existing theories on subject.

IRON CASTINGS

AGING. Transformation of Castings by Time (Transformation de la fonte avec le temps). *Fonderie Moderne (Paris)*, vol. 22, Jan. 25, 1928, pp. 25-26.

Effects of slow cooling; transformation of crystalline structures and modification of structure by annealing; time required to age castings and effect of open air.

IRON AND STEEL

CARBON PENETRATION. On the Mechanism of Carbon Penetration in the Cementation of Iron and Steel, G. Takahashi. *Tohoku Imperial Univ.—Sci. Reports (Sendai)*, vol. 17, no. 4, July, 1928, pp. 761-782, 12 figs. partly on supp. plate.

Writer shows by several experiments that mechanism of carburization in iron and steel is not due to diffusion of carbon monoxide gas, as has been usually believed to be, but to direct diffusion of nascent carbon atoms produced by decomposition of above gas.

CORROSION. The Phenomena of Corrosion of Iron and Steel, A. Herrero and M. de Zubiria. *Iron and Coal Trades Rev. (Lond.)*, vol. 117, no. 3161, Sept. 28, 1928, pp. 434-437, 12 figs.

Theories of corrosion; electrochemical phenomena; table of electropotentials of various metals; causes of corrosion; means of moderating effects of corrosion. Paper presented before Iron and Steel Inst.

HEAT TREATMENT. The Heat Treatment of Ferrous Metals, C. M. Walter. *Chem. and Industry (Lond.)*, vol. 47, no. 31, Aug. 3, 1928, pp. 791-797, 21 figs.

Brief review of whole question of constitution of steel, wrought iron, and cast iron; how such material appears when examined after properly polishing and etching, at high magnification; thermal critical points of steels; thermal-treatment operations; influence of special elements on location of critical temperature ranges; fuels and furnace plant required for heat-treatment work; application of gas-sealed furnaces.

OXYGEN DETERMINATION. The Effect of Oxygen on Iron and Steel. *Metallurgist (Supp. to Engineer, Lond.)*, Aug. 31, 1928, pp. 116-118, 3 figs.

Oxygen can in general be regarded as impurity in iron and steel; its effect is not always in proportion to content but varies with distribution and form in which it is present; solubility of oxygen in pure iron; estimation of oxygen and proportion present in steel. (To be continued.)

OXYGEN DETERMINATION. The Effect of Oxygen on Iron and Steel. *Metallurgist (Supp. to Engr., Lond.)*, Sept. 28, 1928, pp. 130-132, 2 figs.

Structure of oxygen-bearing steels; removal of oxygen by manganese; effect of oxygen on physical and electrical properties. (Continuation of serial.)

LEAD-ANTIMONY ALLOYS

Lead-Antimony Alloys (Sur les alliages plomb-antimoine), W. Broniewski and L. Sliwowski. *Revue de Metallurgie (Paris)*, vol.

25, no. 7, July, 1928, pp. 397-404, 10 figs.

Discusses properties of these alloys, electric and mechanical, and their crystalline structure.

MAGNESIUM-ZINC ALLOYS

Composition of Magnesium-Zinc Alloys (Constitution des alliages de magnésium et de zinc), R. Chadwick. *Fonderie Moderne (Paris)*, vol. 22, Apr. 25, 1928, pp. 139-147, 20 figs.

Study of researches on equilibrium diagram of magnesium-zinc alloys; alloys in which magnesium and zinc are precipitated under form of pyrophosphates; metallographic analysis. Abstract translated from Inst. of Metals—advance paper, previously indexed.

MANGANESE STEEL

Manufacture and Heat Treatment of Manganese Steel, H. P. Evans and A. F. Buritt. *Fuels and Furnaces*, vol. 6, no. 9, Sept. 1928, pp. 1203-1206.

Authors deal with furnace practice both in melting and heat treatment of manganese steel; present basic electric melting practice. Abstract of paper presented before Am. Foundrymen's Assn., previously indexed from Reprint.

MACHINING. Progress in Machining Manganese Steel, A. S. Martin. *Machy. (Lond.)*, vol. 32, no. 827, Aug. 16, 1928, pp. 622-623, 3 figs.

Typical examples of what is being accomplished in way of machining cast and rolled manganese steel; proper tool angles, feeds, and speeds necessary to produce most satisfactory results in each particular operation were determined by means of experiments; shape of drill points; cutting keyways; shaping, planing, and boring operations on manganese steel.

PROPERTIES. A Study of the Mechanical Properties of Low Manganese Steel, M. Hamasumi. *Tohoku Imperial Univ.—Technology Reports (Sendai, Japan)*, vol. 7, no. 4, 1928, pp. 305-330, 17 figs.

Author deals with mechanical properties of 21 low-manganese steels; he explains cold brittleness and blue shortness of steel by newly introduced idea of maximum normal resistance and maximum slip resistance of gliding planes of crystal. (In English.)

STRUCTURE. A Study on the Constitution of High Manganese Steels, V. N. Krivobok. *Am. Soc. Steel Treating—Advance Paper*, no. 22, for mtg. Oct. 8-12, 1928, 37 pp., 37 figs.

Constituents of austenitic manganese steel (Hadfield steel) under different conditions of treatment; cold working followed by heating to certain temperatures, brings about decomposition of original austenite; theory of decomposition; suggestion that allotropic transformation takes place; formation of carbide constituent as influenced by cold working and heating; theory of martensitization; occurrence of martensitic needles in manganese austenite studied.

METALLOGRAPHY

Metallurgy Simplified for Practical Use in Shop, E. Preuss, G. Berndt, M. V. Schwartz. *Iron Trade Rev.*, vol. 83, no. 18, Nov. 1, 1928, pp. 1116-1118, 3 figs.

Critical points and equilibrium diagrams are discussed; equilibrium diagrams can be

determined by heats developed during cooling and heating; explanation of equilibrium diagram of iron-carbon alloys; equilibrium diagram not only permits determination of composition, but also quantitative proportions of melt and solid solutions. (Continuation of serial.)

Metallography Simplified for Practical Use in Shop, E. Preuss, G. Berndt, and M. V. Schwarz. *Iron Trade Rev.*, vol. 83, no. 20, Nov. 15, 1928, pp. 1247-1248, 4 figs.

Explanation of critical points and equilibrium diagrams is completed with definitions for eutectic, hypo-eutectic, and hyper-eutectic alloys of metals; determining amount of single constituents. (Continuation of serial.)

METALS

CORROSION RESISTANCE. Corrosion-Resistant Metals and Alloys. *Chem. Age*, (Lond.), vol. 19, no. 478, Aug. 25, 1928, pp. 157-158.

Importance of protective films; metals of high purity; lead, copper and aluminum; iron and its alloys.

OXIDATION. Oxygen and Metals, F. Johnson. *Foundry Trade J.* (Lond.), vol. 39, no. 635, Oct. 18, 1928, pp. 279-280.

Author discusses relationship in regard to corrosion, differential aeration, passivity, protective character of oxide films, temper colors, surface condition and oxidation, oxidation at high temperature, oxides as physico-chemical phases; surface streaks on polished sheet copper, oxide-rich surface on tough-pitch copper, cause of surface ripples, how oxide particles produce brittleness in cold-worked copper, oxidation in melting of metals, and deoxidation.

TESTING. On Thermal Brittleness in Metals, T. Inokuty. *Tohoku Imperial Univ.—Sci. Reports (Sendai)*, vol. 17, no. 4, July, 1928, pp. 817-842, 18 figs.

Abnormal increase of strength in steels at temperature range of about 200-300 deg. Cent., is usually explained by theory of hardening due to deformation of material; if so, other metals will also show similar phenomenon at certain temperatures; writer made some experiments on aluminum, 4:6 brass, copper, lead, tin, zinc, and Armco iron, and confirmed above conclusion.

TESTING. Strain Figures of Various Specimens, Z. Takenaka. *Soc. Mech. Engrs.—Jl.* (Tokyo), vol. 31, no. 135, July, 1928, pp. 275-285, 22 figs.

According to Fry's process, strain figures for various specimens under various loads are shown; strain produced by punching hole, case of drilling a hole; few examples of etching solutions with which satisfactory results obtained are given.

TESTING. Machines for Testing Metals (Les machines pour l'essai des métaux). *Revue Industrielle (Paris)*, vol. 58, nos. 2226, 2227, 2228, 2229 and 2230, May, June, July, Aug. and Sept., 1928, pp. 259-271, 317-327, 389-394, 461-467 and 528-530, 58 figs.

May: Tensile testing machines of several kinds are described; extensometers of mechanical and optical types. June: Hardness-testing machines using levers and hydraulic means; apparatus to measure Brinell indentations; Shore, Herbert and Rockwell machines. July: Shock-testing and forming machines. Aug.: Testing by folding; torsion testing;

endurance and repeated-effort machines. Sept.: Testing for wear.

TESTING. Rapid Determination of Endurance Strength (Die Schnellbestimmung der Dauerwechselfestigkeit), O. v. Bohuszewicz and W. Spaeth. *Archiv fuer das Eisenhuettenwesen (Berlin)*, vol. 2, no. 4, Oct., 1928, pp. 249-254 and (discussion) p. 255, 12 figs.

Description of rapid method based on static and dynamic torsional stress; recording of static and dynamic curves; examples are given of number of technical materials, including brass, cast iron, open-hearth steel, tool steel, chromium-nickel steel, and duralumin.

TESTING. The Mechanical Testing of Metals, T. F. Russell. *Metal Industry (Lond.)*, vol. 33, no. 10, Sept. 7, 1928, pp. 221-225, 8 figs.

Whitworth tensile testing machine; transverse and bending tests. (Continuation of serial.)

TESTING. Statics of Failure by Repeated Stress (Statische Grundlagen zum Schwingungsbruch), W. Kuntze. *V. D. I. Zeit.* (Berlin), vol. 72, no. 42, Oct. 20, 1928, pp. 1488-1492, 8 figs.

Report from government testing laboratory of Dahlem, near Berlin, on experimental study of deformation phenomena and decrease in tensile strength of silicon steel, duralumin, copper, brass, etc.

TORSIONAL MODULUS. Torsional Modulus of Carbon Steel Phosphor Bronze, Brass, and Monel Metal, W. P. Wood. *Am. Soc. Steel Treating—Advance Paper*, no. 31, for mtg. Oct. 8-12, 1928, 12 pp., 1 fig.

Torsional modulus of elasticity is defined and its general relation to modulus of elasticity in tension and compression is discussed; review of published work on determination of torsional modulus; four methods of determining torsional modulus; determinations were made upon three types of steel, phosphor bronze, brass, and monel metal; results given in form of averages.

MICROSCOPES

METALLURGICAL. The Use of the Microscope in Heat Treatment, H. M. Boylston. *Fuels and Furnaces*, vol. 6, no. 10, Oct., 1928, pp. 1377-1382.

Reviews development made in field of microscopic study in last 36 years and describes development of apparatus technique, materials, etc.; author points out importance of microscope as guide in all heat-treating processes, including annealing, hardening, tempering, carburizing, etc.

MOLYBDENUM STEEL

EQUILIBRIUM DIAGRAM. On the Equilibrium Diagram of the Iron-Molybdenum System, T. Takei and T. Murakami. *Am. Soc. Steel Treating—Advance Paper*, no. 30, for mtg. Oct. 8-12, 1928, 20 pp., 35 figs.

Equilibrium diagram of iron-molybdenum system studied by microscopic investigation, electric resistance method, and by dilatometric and magnetic analyses; in this system, two intermetallic phases, epsilon and eta, exist; solubility of molybdenum in alpha iron; in alloys containing more than 63 per cent of molybdenum, eutectoid is found, consisting of eta-phase and molybdenum dissolving iron.

MONEL METAL

OXYACETYLENE WELDING. Welding of

Monel Metal and Some Applications (La soudure du métal Monel et quelques-unes de ses applications). *Soudeur-Coupeur (Liège)*, vol. 7, no. 8, Aug., 1928, pp. 87-89, 5 figs.

Characteristics and composition of Monel metal and uses; treatment of metal before welding by oxyacetylene blowpipe; examples of welding.

WELDING. Welding Monel Metal and Nickel. C. A. Crawford and J. G. Schoener. *Sheet Metal Worker*, vol. 19, no. 18, Sept. 7, 1928, pp. 585-586, 4 figs.

Successful welds largely dependent upon observing certain conditions; briefly identifies monel metal and pure nickel of commercial use; compares monel metal and nickel; methods of welding; oxyacetylene welding; good fluxing required. (To be continued.)

NICKEL

UTILIZATION. Nickel and Its Applications (Le nickel et ses applications). L. Guillet. *Union des Ingénieurs sortis des Ecoles Spéciales de Louvain—Bul. Technique (Louvain)*, vol. 55, no. 2, Aug. 25, 1928, pp. 1-22.

Reviews present state of nickel metallurgy and describes pure nickel and how utilized in iron and steel works and in non-ferrous metals; nickel plating; nickel alloys to prevent corrosion.

NICKEL ALLOYS

ACID RESISTING. Acid-Resisting Nickel Alloys. *Chem. Age, (Lond.)*, vol. 19, no. 478, Aug. 25, 1928, p. 158.

Large range of useful products; nickel-chromium stainless steels; nickel-copper alloys.

NICKEL PLATING

Cadmium and Nickel Plating of Small Parts. F. W. Curtis. *Am. Mach.*, vol. 69, no. 11, Sept. 13, 1928, pp. 437-440, 8 figs.

Operating equipment and methods used in plant of Bassick Mfg. Co., Chicago, in plating screw-machine products and metal stampings of steel and brass, are described; most of work performed automatically.

NICKEL STEEL CASTINGS

Critical Points and Martensitic Tempering of Nickel and Nickel-Chromium Castings. (Sur le points critiques et la trempe martensitique des fontes au nickel et au nickel-chrome). L. Guillet, Galibourg and Ballay. *Académie des Sciences—Comptes Rendus (Paris)*, vol. 187, no. 1, July 2, 1928, pp. 14-16.

Tempering tests showed that silicon raises transformation temperature, and therefore increases critical rate of tempering but diminishes tendency both for primary and secondary tempering; manganese, nickel and chromium have reverse effect on secondary tempering, tendency for primary tempering is unaffected by manganese and diminished by nickel.

NON-FERROUS CASTINGS

TEST BARS. Test Bars for Non-Ferrous Metals (Eprouvettes pour métaux autres que le fer). I. S. Darnis. *Revue de Métallurgie (Paris)*, vol. 25, no. 8, Aug., 1928, pp. 457-460, 8 figs.

Shows influence of certain factors for bronze test bars run in mold under varying condi-

tions; results of tension tests on such bars; discusses relations of test bar and piece itself. Abstract of paper presented before Int. Foundry Congress.

OPEN HEARTH FURNACES

BASIC. Forty Years' Experience in Development of Open-Hearth Process. B. Talbot. *Iron and Steel of Can. (Gardenvale, Que.)*, vol. 11, no. 9, Sept., 1928, pp. 266-270.

Account of personal experience in development of basic process; development of acid process in United States; shows sectional elevation of author's new design of open-hearth furnaces with auxiliary hearths; process absorbs vast quantities of miscellaneous scrap without being necessary to select it by analysis. Abridgement of presidential address before Iron and Steel Inst., previously indexed.

DESIGN—UNITED STATES. Information on Construction of Open-Hearth Furnaces in United States (Données sur la construction des fours Martin aux Etats-Unis). F. Leperonne. *Revue Universelle des Mines (Liège)*, vol. 19, no. 3, Aug. 1, 1928, pp. 109-123, 9 figs.

Types and capacities of furnaces; description of stationary furnaces, their foundations and lining; doors; brick lining and lining of clay of magnesia; cooling of masonry; recuperators and dust chambers; mean life of different parts of furnaces.

PICKLING (METALS)

Pickling Influences the Spangle of Zinc-Coated Sheets. W. G. Imhoff. *Iron Trade Rev.*, vol. 83, no. 13, Sept. 27, 1928, pp. 768-769 and 780, 5 figs.

Certain qualities in base metal essential for development of suitable finishes are discussed; pickling of steel influences development of spangle; good steel properly pickled will develop large fern-like spangle; factors causing small granular spangles originally develop in steel-making process; only possible means still available to eliminate them entirely is to use good inhibitor.

INHIBITORS. Inhibitors Reduce Pickling Vapors. *Kremer. Iron Trade Rev.*, vol. 83, no. 14, Oct. 4, 1928, p. 841.

Inhibitor added to pickling liquid in small quantities alters qualities of mineral acids in such a way that they do not attack metallic iron while oxide film is dissolved completely during pickling process; chief source of injuries to health eliminated; saving of pickling material and baskets.

RAILS

ALLOY STEELS. Special Steels and Wear of Rails on Street Railroads (Les aciers spéciaux et l'usure des appareils de voies de tramways). Marthourey. *Revue Industrielle (Paris)*, vol. 58, no. 2230, Sept., 1928, pp. 540-547, 6 figs.

Author discusses action of special steels used in street-railroad rails and defines various characteristics of steels; future steels and special treatments; electric nickel-chrome steel.

CHROMIUM-STEEL. Chromium Steel for Railroad Rails. *Iron Age*, vol. 122, no. 14, Oct. 4, 1928, pp. 826-827.

High-manganese and Bessemer steel rails also defended by metallurgists at meeting of

Brit. Iron and Steel Inst.; low alloy gives prolonged life under heavy traffic; it was found that chromium-steel rails as rolled were capable of being drilled without difficulty and would not air-harden after heating for bending; higher carbon reduces impact resistance; manganese in carbon steel could safely go to 1 per cent.

TRANSVERSE FISSURES. Concerning Rail Tread Fissures, H. Viteaux. *Metallurgist* (Supp. to *Engineer*, Lond.), Aug. 31, 1928, pp. 127-128.

Conclusions have been drawn that for equal width and depth, fissures, whether produced by cold working or by auto-quenching are equally harmful, and that there is grave danger in existence of large tonnages of rails on roads, e. g., in Lorraine district, with treads which are cold worked and fissured. Translated from *Revue de Métallurgie*, Sept., Oct., Nov., 1927. (Concluded.)

RAIL STEEL

STRUCTURE. Some characteristics of Pearlite in Eutectoid Rail Steels, O. V. Greene. *Am. Soc. Steel Treating—Advance Paper*, no. 13, for mtg. Oct. 8-12, 1928, 19 pp., 20 figs.

Results of tests made on rail steels of eutectoid composition; N. T. Belaiew's method used for explaining apparent difference in nature of pearlite; condition of pearlite dependent not on carbon content but on velocity of cooling; definite relation exists between Brinell hardness and distance between lamellae; equations are developed showing Brinell hardness as function of both distance between lamellae and ultimate tensile strength.

ROLLING MILL PRACTICE

EUROPE. Rolling Thin Sheets, W. Kramer. *Iron and Steel World*, vol. 2, no. 6, June, 1928, pp. 287-292, 5 figs.

Discussion of European rolling-mill practice; author deals with existing plants and processes, touches upon some of important innovations during recent years, and offers suggestions for further improvements. From *Stahl u. Eisen*.

SHAFTING, STEEL

COLD ROLLED. Qualities of Cold Rolled Shafting, J. R. Miller. *Iron Age*, vol. 122, no. 11, Sept. 13, 1928, p. 637, 1 fig.

Comparisons of cold-rolled shafting with cold-drawn steel; design of groove for rolling; typical steel analyses.

SHEET STEEL

COLD ROLLING. Influence of Cold Rolling and Annealing at Different Temperatures on the Strength and Structure of High-Grade Sheets (Der Einfluss des Kaltwalzens und Gluehens bei verschiedenen Temperaturen auf die Festigkeitseigenschaften und das Gefuege von Qualitaetsfeinblechen), E. Marke. *Archiv fuer das Eisenhuettenwesen* (Duesseldorf), vol. 2, no. 3, Sept., 1928, pp. 177-183 and (discussion) 183-184, 16 figs.

Results of tests to determine mechanical properties and structure of cold-rolled sheet, and cold-rolled sheet subsequently annealed; practical application of results in sheet mills.

HEAT TREATMENT. Normalizing Sheet Steel, W. Parker. *Iron and Coal Trades Rev.*

(Lond.), vol. 117, no. 3160, Sept. 21, 1928, pp. 397-398, 2 figs.

Demand for ductile steel, particularly by automobile industry, has made it difficult for steel mills to meet exacting requirements of users; new method, evolved in United States, being introduced by British Furnaces, Ltd.; continuous annealing furnace illustrated and described; uniform results are not obtainable where box annealing is employed; when using coke-oven gas, debited at 10 cents per 1000 cu. ft., cost per ton of annealed sheets is \$1.50; box annealing cost \$3.00 per ton.

SILVER—ALUMINUM ALLOYS

Aluminum Silver Alloys, M. Hansen. *Metallurgist* (Supp. to *Engr.*, Lond.), Sept. 28, 1928, pp. 135-136.

Constitution of aluminum-silver alloys was investigated in 1905 by Petrenko, who showed that silver was insoluble in aluminum; aluminum-rich end of diagram was reinvestigated by author who found that in neighborhood of eutectic temperature, 558 deg. Cent., aluminum dissolves 48 per cent of silver and at 200 deg. 0.75 per cent. Very brief abstract translated from *Zeit. fuer Metallkunde*, June, 1928, previously indexed.

SMALL ARMS

HEAT TREATMENT. Heat Treatment and Finish of Small Arms at Springfield Armory, P. W. Oliver. *Army Ordnance*, vol. 9, no. 49, July-Aug., 1928, pp. 28-32, 3 figs.

Heat treatments and finishes described in this article deal principally with those which are given to components of U. S. Rifle, caliber 30, Model 1903; list of metal components of service rifle together with class of steel used in these components; annealing furnaces of several sizes and designs; types of finishes used on various components are, parkerizing, oil blackening, niter bluing and browning.

SPRINGS

HEAT TREATMENT. Hardening Springs for Elasticity, *Wire*, vol. 3, no. 10, Oct., 1928, pp. 338-339 and 355, 3 figs.

Modulus of elasticity; science of spring making; heat treatment; tempering and inspection; correct hardness; uniform hardness imperative.

STAINLESS IRON

NITRIC ACID HANDLING. Stainless Iron and Its Application to the Manufacture and Transportation of Nitric Acid, W. M. Mitchell. *Am. Soc. Steel Treating—Advance Paper*, no. 26, for mtg. Oct. 8-12, 1928, 24 pp.

Development of stainless irons, because of their importance to chemical industries as materials for handling of nitric acid; importance of this acid as source of available fixed nitrogen; recently developed ammonia-oxidation process for manufacture of nitric acid; resistance of various materials to nitric acid and superiority of high-chromium alloys; requirements for construction of equipment for manufacture and transportation of nitric acid.

AIRCRAFT—TESTING. Stainless Iron for Naval Aircraft, E. Joyce. *Iron Age*, vol. 122, no. 11, Sept. 13, 1928, pp. 627-630.

Results of investigation of suitability of two types of stainless iron for naval aircraft construction, made at Naval Aircraft

Factory, are recorded; physical and anti-corrosion properties reported on favorably; good fabricating and machining qualities; precautions in welding, machining and heat treatment; tensile properties in annealed condition better than those of mild steel.

STAINLESS STEEL

Rust, Acid and Heat-Resisting Steels, W. H. Hatfield. *Am. Iron and Steel Inst.—Advance Paper for mtg.*, Oct. 26, 1928, 14 pp.

Properties of series of steels, which are adequate to meet many conditions where rust, acids, or heat effects must be resisted, are discussed; production of rustless and acid-resisting steels should always be conducted under best technical control; possibilities of these steels will largely be governed by cost of production; undoubtedly great future in their application.

AIRCRAFT. Stainless Steel for Aircraft, F. Sigrist. *Flight (Lond.)*, vol. 20, no. 39, Sept. 27, 1928, pp. 834b-834d, 2 figs.

Stainless steel available in form of sheet, bar, tube, strip, forgings, and castings; hard and soft sheets used; precautions for nibbling, filing, bending, drilling, sawing, drawing, pressing, soldering, and brazing; machining bar material; saving in using stainless plate instead of high-tensile sheet; finish on plate work.

STEEL

ABNORMAL Aluminum in the Mold Makes Abnormal Steel, S. Epstein and H. S. Rawdon. *Iron Age*, vol. 122, no. 20, Nov. 15, 1928, p. 1220.

Results of investigation of problem of abnormal steel as indicated by McQuaid-Ehn carburizing test, made by Bureau of Standards; conclusion reached that abnormality is largely due to method of finishing heat of steel; when plain carbon steel is still wanted, metallurgists may specify normal steel to avoid soft spots, as it is more likely to harden uniformly, and carburizes somewhat faster. Abstract of Bureau of Standards Research Paper No. 14.

AIRCRAFT. Steel Requirements of the Aircraft Industry, H. J. French. *Am. Iron and Steel Inst.—Advance Paper for mtg.*, Oct. 26, 1928, 38 pp., 26 figs.

Tonnage requirements for steels for aircraft construction will probably remain small part of total steel production; production aspects; general technical requirements; typical steel practice and applications; steel, wood, and duralumin aircraft construction; steels will probably continue as one of principal metals of construction; demand will be for materials of super-quality. See abstract in *Iron Trade Rev.*, vol. 83, no. 18, Nov. 1, 1928, pp. 1105-1108 and 1118, 9 figs.

ANALYSIS—VANADIUM DETERMINATION. A New Precipitation Method for the Determination of Vanadium, and its Application to Steel Analysis, B. S. Evans and S. G. Clarke. *Analyst (Lond.)*, vol. 52, no. 630, Sept. 1928, 475-486.

Process described in addition to materially shortening time required, has also been applied to determination of amounts lower than have previously been attempted; determination in steel; process does not require separation of any elements other than nickel; tests of process.

HEAT TREATMENT. Facts and Principles

Concerning Steel and Heat Treatments, H. B. Knowlton. *Am. Soc. Steel Treating—Trans.*, vol. 14, no. 4, Oct., 1928, pp. 580-608.

Article discusses various special types of heat-treating furnaces including continuous furnaces, liquid baths, furnaces depending upon critical point, special tempering furnaces, etc.; various schemes of quenching, regulation of temperature of quenching bath, and conveying and handling systems are discussed; suggestions concerning layout of heat-treating department and personnel necessary for successful operation. (Continuation of Serial.)

HEAT TREATMENT. Principles of the Heat Treatment of Steel. *Am. Soc. for Steel Treating—Trans.*, vol. 14, no. 4, Oct., 1928, pp. 502-538, 11 figs.

Outline prepared by Metallurgist staff of Bur. of Standards; factors to be considered in heat treatment; effect of heat on high-carbon steel, on steel of low and medium carbon content, and on iron; effect of composition; names and structure of constituents of steel; annealing and normalizing; spheroidizing. (To be continued.)

HEAT TREATMENT—QUENCHING. Effect of Quenching Temperature Change on the Properties of Quenched Steel, O. W. McMullan. *Am. Soc. Steel Treating—Trans.*, vol. 14, no. 4, Oct., 1928, pp. 477-501, 24 figs.

Comparison of hardness results obtained by different testers is shown plotted against Vickers hardness as standard; results noted are that maximum surface hardness on high-carbon steels is obtained at low quenching temperatures; maximum center hardness of quenched steel occurs at much higher temperatures along with more or less sudden increase in grain size; marked effect of low temperature draw on hardness and other physical properties of core of S.A.E. 1020 steel.

STEEL CASTINGS

Comparison of Steel Castings with Gray-Iron and Malleable Castings (Die Verwendbarkeit des Stahlgusses im Vergleich zu Grauguss und Temperguss), F. Herkenrath. *Gieserei (Duesseldorf)*, vol. 15, no. 40, Oct. 5, 1928, pp. 993-996.

Author claims that gray cast iron presents little competition to steel castings; on other hand malleable cast iron is a formidable competitor.

LARGE. A Very Large Steel Casting. *Engineer (Lond.)*, vol. 146, no. 3797, Oct. 19, 1928, p. 442, 2 figs.

What is believed to be largest steel casting yet made has been completed by Cammell Laird and Co., Ltd., of Sheffield; combined haulage capacity of five road engines was required to transport it; casting is anvil block for friction drop stamp designed for use with 5-ton tup.

TUBE MILLS

Timken Steel and Tube Company. *Blast Furnace and Steel Plant*, vol. 16, no. 10, Oct., 1928, p. 1329.

Subsidiary is formed to facilitate production and sale of bars and tubing of Timken quality steel; steel has special applications; equipment for bars and tubes; seamless tubes; treatment and inspection.

News of the Society

THE WESTERN METAL CONGRESS

DETAILS of arrangements are rapidly being completed for the Western Metal Congress and the Western States Metal and Machinery Exposition, to be held in Los Angeles the week of January 14, 1929, under the auspices and direction of the American Society for Steel Treating.

In the December issue of TRANSACTIONS was published a list of those individuals and companies who had already reserved space for their exhibit in the Shrine Civic Auditorium. That list has been much enlarged and appears on the following pages of this issue of TRANSACTIONS.

The tentative technical program is likewise published in this issue. It will require only a glance at this array of interesting technical contributions to realize that the program committee under the chairmanship of W. H. Laury has done an admirable piece of work.

Participating in these will be the American Society of Mechanical Engineers, American Institute of Mining and Metallurgical Engineers, California Division of Development and Production Engineering of the American Petroleum Institute, American Welding Society, Society of Automotive Engineers, Pacific Coast Electrical Association, Pacific Coast Gas Association, Institute of Marine Engineers, Metal Trades and Manufacturers Association, Chamber of Mines and Oils, National Purchasing Agents Association and the American Society for Steel Treating.

If you have not already made your railroad and hotel reservations it would be advisable to do so immediately as there is much demand for hotel accommodations as well as railroad facilities. The Santa Fe Railroad in cooperating with the society by running a special train or trains, leaving Chicago January 7, 1929, arriving in Los Angeles Saturday afternoon, January 13. These special arrangements provide for a one-day stop-over at the Grand Canyon. The Hotel Biltmore will be the headquarters for the American Society for Steel Treating.

TENTATIVE TECHNICAL PAPERS PROGRAM

MONDAY, JANUARY 14

Morning Session—10:00 A. M.

Meeting in Hotel Biltmore

Chairman—Prof. W. H. Clapp, department of metallurgy and machine design, California Institute of Technology, Pasadena, California.

- 1 *The Importance of Shops in University Training*—Arthur B. Domonoske, executive head Mechanical Engineering Department, Stanford University.
- 2 *Gear Manufacturing, including Heat Treatment*—F. A. Brooks, chief engineer, Johnson Gear Co., Berkeley, California.

- 3 *Investigation of Fatigue Resistance of Eutectoid Carbon Steel when Drawn at Different Temperatures*—R. M. Watson, metallurgist, Regan Forge Co., San Pedro, California.
- 4 *Heat Treatment of Dies, Tools and Gears*—Jordan Korp, Leeds and Northrup Co., Philadelphia.

Afternoon Session—2:00 P. M.

Meeting in Shrine Auditorium

Chairman—Carroll A. Stilson, Foundry Division Program, sponsored by Metal Trades and Manufacturers Association.

- 1 *Special Nickel Castings*—Paul D. Merica, assistant manager, research bureau, International Nickel Company, New York.
- 2 *Sand Testing Equipment and Demonstration*—A. A. Grubb, Mansfield, Ohio, (member of A. F. A., Sand Testing Committee).
- 3 *Nickel-Chrome Alloy Iron*—W. R. Shimer, metallurgical engineer, Bethlehem Steel Corporation, Bethlehem, Pa.
- 4 *Heat Treatment of Carbon and Alloy Steel Castings*—J. E. Donnellan, secretary Recommended Practice Committee of the American Society for Steel Treating, Cleveland.
- 5 *Furnaces*—R. E. Talley, president, George J. Hagan Co., Pittsburgh.

TUESDAY, JANUARY 15

Morning Session—10:00 A. M.

Meeting in Hotel Biltmore

- 1 *Selecting Metals and Alloys for Severe Services Involving Corrosion, Erosion, and Heat Resistance, with Particular Reference to Oil Refinery Conditions*—Jerome Strauss, Vanadium Corporation of America, Bridgeville, Pa.
- 2 *Valves and Fittings in the Oil Refinery, the Materials used in Their Construction, Their Design, and Their Application in Particular Services, and High Pressure Oil Conveying and High Pressure Gas Distribution*—V. T. Malcolm, metallurgical engineer, Chapman Valve Co., Indian Orchard, Mass.
- 3 *Tendency toward Higher Steam Pressures in Both Marine and Stationary Services, the Materials Available for the Construction of Boilers for these Higher Pressures, and some of the Factors Involved in their Design*—Robert L. Daugherty, Professor of Mechanical Engineering, California Institute of Technology.
- 4 *Heat, Refractories and Insulation*—Guy E. Barker, manager industrial department, Johns Manville, Inc.

Afternoon Session—2:00 P. M.

Meeting in Shrine Auditorium

H. H. Anderson, Chairman. Mr. Anderson is Chairman of the Program Committee of the American Society of Mechanical Engineers. This meeting will consist of a symposium of five papers on the manufacture of oil field specialties.

- 1 *Tool Joints*—E. W. Goesor, chief engineer, Emseo Derriek and Equipment Company, Los Angeles.
- 2 *Cast Steel Slush Pump Cylinders*—Lester Keim, Oil Well Supply Company of California.
- 3 *Kellys, or Grief Stems*—E. W. Timbs, National Supply Co.
- 4 *Sucker Rods*—W. H. Laury, metallurgist, Axelson Machine Co.
- 5 *Heat Treated Drill Pipe*—Standard Seamless Tube Co.

WEDNESDAY, JANUARY 16**Morning Session—10:00 A. M.**

Meeting in Hotel Biltmore

American Petroleum Institute, California Division of Development and Production Engineering, A. C. Rubel, District Chairman, Union Oil Company, T. E. Swigart, National Vice-Chairman, Shell Company.

- 1 *Sucker Rod Strains and Stresses*—F. W. Lake, Union Oil Co.
- 2 *Drill Pipe Failures*—Ben Stroud, National Tube Company.
- 3 *Casing Failures*—K. V. King, of Standard Oil Co. of California.
- 4 *Welding and High Pressure Gas Distribution*—C. J. Coberly, of Kobe, Incorporated.

Afternoon Session—2:00 P. M.

Meeting in Shrine Auditorium

American Institute of Mining and Metallurgical Engineers, Glenn Robertson, Associated Oil Co., Chairman of Program Committee and Secretary. R. R. Boyd, Chairman of the Group, Richfield Oil Co.

- 1 *On the Double Diagram of the Iron-Carbon System*—Dr. Kotaro Honda, Research Institute for Iron and Steel, Imperial University, Sendai, Japan.
- 2 *Proposed Metallurgical Control for Small Heat Treating Plants*—Dr. Welton Crook, Professor of Metallurgy, Stanford University.
- 3 *Electro Plating and the Uses of Copper in Machinery*—Speaker to be announced later.
- 4 *Heat Treatment of Gears*—W. H. Phillips, vice president, Molybdenum Corporation of America, Pittsburgh.

THURSDAY, JANUARY 17**Morning Session—10:00 A. M.**

Meeting in Hotel Biltmore

C. M. Grow, Chairman of the Program Committee of the Pacific Coast Gas Association and business manager of the Southern California Gas Association.

- 1 *Gas and Electricity as Heating Mediums*—F. W. Manker, vice-president, Surface Combustion Company, Toledo, Ohio.
- 2 *Heat Treating Furnace Design*—J. H. Gumz, industrial engineer, Pacific Gas and Electric Corporation, San Francisco.
- 3 *Existing Heat Treating Installations*—E. M. DeReamer, industrial engineer, Southern California Gas Company, Los Angeles.
- 4 *What the Gas Companies are Doing For Industrial Heating*—C. M. Grow, new business manager, Southern California Gas Company, Los Angeles.
- 5 *Gas as Applied to Carburizing*—Robert G. Guthrie, metallurgist, Peoples Gas Light and Coke Company, Chicago.

Afternoon Session—2:00 P. M.

Meeting in Shrine Auditorium

R. C. McFadden, Chairman. Mr. McFadden is the new business manager of the Southern California Edison Co., and active in the work of the Pacific Coast Electrical Association.

- 1 Address—Paul Downing, vice president, Pacific Gas and Electric Corporation, and President of the Pacific Coast Electrical Association.
- 2 "*Electric Heat as Applied to Industry*"—C. L. Ipsen, consulting and designing engineer of the industrial and welding department of the General Electric Company.

- 3 *Design as Applied to Arc Welded Construction*—Gilbert D. Fish, Westinghouse Electric and Manufacturing Company.

FRIDAY, JANUARY 18

Morning Session—10:00 A. M.

Meeting in Hotel Biltmore

Ethelbert Favary, Chairman of the Program Committee of the Society of Automotive Engineers and connected with the Moreland Motor Truck Co.

- 1 *Manufacture and Heat Treatment of Automobile Leaf Springs*—J. B. Rauert, general manager of the U. S. Spring Company, Los Angeles.
- 2 *Production of Nickel Steel Castings by Electric Furnace Method*—E. Favary, consulting engineer, Moreland Truck Company.
- 3 *Aluminum as Applied to the Automotive and Airplane Industry*—Dr. Zay Jeffries, chief research engineer, Aluminum Company of America, Cleveland.
- 4 *Some Phases of Air craft Construction*—Speaker to be announced.
- 5 *Metallurgical and Heat Treating Problems in Motor Car Manufacture* (illustrated with moving pictures)—J. M. Watson, chief metallurgist, Hupp Motor Car Company.

Afternoon Session—2:00 P. M.

Meeting in Shrine Auditorium

A. E. Deburn, Chairman of the Program Committee of the American Welding Society and connected with the Pacific Pipe and Supply Co.

- 1 *The Welding of Steel Buildings and Bridges*—Dr. Frank P. McKibbin, consulting engineer for the General Electric Company, at which meeting the American Society of Civil Engineers, American Institute of Electric Engineers, and the American Institute of Architects will participate.
- 2 *Heat Treatment with Oxyacetylene Flame*—J. J. Bruton, service engineer, Oxweld Acetylene Company, New York.
- 3 *Building Machinery with Arc Welded Steel Replacing Castings*—David Hall, district engineer, Westinghouse Electric and Manufacturing Company, Los Angeles.

The following is a complete list of exhibitors as of December 10, 1928, of those companies and individuals who will have exhibits at the Western States Metal and Machinery Exposition at Los Angeles, California.

ABRASIVE COMPANY	Philadelphia
AHLBERG BEARING COMPANY OF CALIFORNIA	Los Angeles
AIR REDUCTION SALES COMPANY	New York
ALCORN COMBUSTION COMPANY	Philadelphia
AMERICAN BRASS COMPANY	Waterbury, Conn.
AMERICAN CAR AND FOUNDRY COMPANY	New York City
ARMSTRONG-BLUM MANUFACTURING COMPANY	Chicago
ARMSTRONG BROTHERS TOOL COMPANY	Chicago
ATKINS AND COMPANY, E. C.	Indianapolis
ATLAS STEEL CORPORATION	Dunkirk, N. Y.
AXELSON MACHINE COMPANY	Los Angeles
BAUSCH AND LOMB OPTICAL COMPANY	Rochester, N. Y.
BETHLEHEM STEEL COMPANY	Bethlehem, Pa.
BLACK AND DECKER MANUFACTURING COMPANY	Towson, Md.
BOTFIELD REFRACTORIES COMPANY	Philadelphia
BRISTOL COMPANY	Waterbury, Conn.

BROWN INSTRUMENT COMPANY	Philadelphia
BUFFALO FORGE COMPANY	Buffalo
BUREAU OF POWER AND LIGHT (L. A.)	Los Angeles
CALIFORNIA MALLEABLE CASTINGS COMPANY	Los Angeles
CALORIC ELECTRICAL CORPORATION	
CARBORUNDUM COMPANY ABRASIVES	Niagara Falls, N. Y.
CARBORUNDUM COMPANY REFRACTORIES	Perth Amboy, N. J.
CENTRAL ALLOY STEEL CORPORATION	Massillon, Ohio
CHICAGO STEEL AND WIRE COMPANY	Chicago
CLARK TRUCTRATOR COMPANY	Battle Creek, Mich.
CLEVELAND TWIST DRILL COMPANY	Cleveland
COLONIAL STEEL COMPANY	Los Angeles
COOPER HEWITT ELECTRIC COMPANY	Hoboken, N. J.
CRUCIBLE STEEL COMPANY OF AMERICA	New York City
DEARBORN CHEMICAL COMPANY	Chicago
DINGS MAGNETIC SEPARATOR COMPANY	Milwaukee
DISSTON AND SONS, HENRY	Philadelphia
DOHENY-STONE DRILLING COMPANY	Glendale, Calif.
DUCOMMUN CORPORATION	Los Angeles
EASON AND THEROFF	Los Nistos, Calif.
EASTMAN KODAK COMPANY	Rochester
ELECTRICAL REFRACTORIES COMPANY	East Palestine, Ohio
ELECTRIC STEEL AND MANUFACTURING COMPANY	Los Angeles
FEDERAL WELDER AND MACHINE COMPANY	Warren, Ohio
FIRTH-STERLING STEEL COMPANY	Los Angeles
FORD COMPANY, J. B.	Wyandotte, Mich.
FUSION WELDING CORPORATION	Chicago
GAIRING TOOL COMPANY, INC.	Detroit
GATHMANN ENGINEERING COMPANY	Baltimore, Md.
GENERAL ELECTRIC COMPANY	Los Angeles
GLOBAR CORPORATION	Niagara Falls, N. Y.
GODDARD AND GODDARD COMPANY	Detroit
HAGAN FURNACE COMPANY	Pittsburgh
HALCOMB STEEL COMPANY	Syracuse, N. Y.
HAYNES STELLITE COMPANY	Kokomo, Ind.
HEPPENSTALL FORGE AND KNIFE COMPANY	Pittsburgh
HERBERTS MACHINE AND SUPPLY COMPANY	Los Angeles
HOUGHTON AND COMPANY, E. F.	Philadelphia
HUGHES TOOL COMPANY	Los Angeles
JOHNS-MANVILLE COMPANY	Los Angeles
JOHNSON GEAR COMPANY	Berkeley, Calif.
JORGENSEN COMPANY, EARLE M.	Los Angeles
KAY-BRUNNER STEEL CASTINGS COMPANY	Los Angeles
KEESE ENGINEERING CORPORATION	Hollywood, Calif.
KELLY REAMER COMPANY	Cleveland
KNAPP COMPANY, JAMES H.	Los Angeles
KRUPP NIROSTA CORPORATION	Los Angeles
L. A. AUTOMOTIVE WORKS	Los Angeles
LEEDS AND NORTHRUP COMPANY	Philadelphia
LEITZ, INCORPORATED, E.	New York City
LINCOLN ELECTRIC COMPANY	Cleveland
LINDE AIR PRODUCTS COMPANY	New York City
LUDLUM STEEL COMPANY	Watervliet, N. Y.
MACHINISTS' TOOL AND SUPPLY COMPANY	Los Angeles
MASTERSON, AND COMPANY, JOS. A.	Los Angeles
MCGILL METAL COMPANY	Valparaiso, Ind.
MERCO NORDSTROM VALVE COMPANY	San Francisco
METTLER COMPANY, LEE B.	Los Angeles
MEYER MACHINERY COMPANY	Los Angeles

- MINERAL AND PRODUCTS CORPORATION
 MORSE TWIST DRILL AND MACHINE COMPANY
 NATIONAL TWIST DRILL AND TOOL COMPANY
 NEW DEPARTURE MANUFACTURING COMPANY
 NORMA-HOFFMAN BEARINGS COMPANY
 NORTHWESTERN MANUFACTURING COMPANY
 NUTTALL COMPANY, R. D.
 OAKITE PRODUCTS, INC.
 OIL BULLETIN
 PACIFIC ABRASIVE SUPPLY COMPANY
 PACIFIC COAST STEEL COMPANY
 PACIFIC FACTORY
 PANGBORN CORPORATION
 PENTON PUBLISHING COMPANY
 PERFECT CASTER MANUFACTURING COMPANY
 PERIN, IRA G.
 PETROLEUM NEWS
 PIER AND COMPANY, A. H.
 PLUMB TOOL COMPANY
 P. L. AND N. COMPANY
 PUROX COMPANY
 REGAN FORGE AND ENGINEERING COMPANY
 SHELL OIL COMPANY
 SIMONDS SAW AND STEEL COMPANY
 SLEEPER AND HARTLEY, INC.
 SMITH-BOOTH-USHER COMPANY
 SNYDER FOUNDRY SUPPLY COMPANY
 SONNTAG SHEAR COMPANY
 SOUTHERN CALIFORNIA EDISON COMPANY
 SOUTHERN CALIFORNIA GAS COMPANY
 SOUTHERN CALIFORNIA IRON AND STEEL
 SPENCER TURBINE COMPANY
 SPINDLER AND SAUPPE
 STANDARD OIL COMPANY
 STANDARD TOOL COMPANY
 STEEL PUBLICATIONS
 STERLING ELECTRIC MOTORS, INC.
 STOODY COMPANY
 STRAND AND COMPANY, N. A.
 TIMKEN STEEL AND TUBE COMPANY
 UNION DRAWN STEEL COMPANY
 U. S. ELECTRICAL MANUFACTURING COMPANY
 VANADIUM CORPORATION OF AMERICA
 VERNON FOUNDRIES
 VICTOR OXY-ACETYLENE COMPANY
 WELDING ENGINEER
 WESTERN COAST PIPE AND STEEL COMPANY
 WESTERN DROP FORGE COMPANY
 WESTERN MACHINERY WORLD
 WESTINGHOUSE ELECTRIC AND MANUFACTURING CO.
 WHITMAN BARNES-DETROIT CORPORATION
 WHITNEY MANUFACTURING COMPANY
 WILCOX COMPANY, E. A.
 WILSON-MAEULEN COMPANY
 WISCONSIN ELECTRIC COMPANY, INC.
 WILSON WELDER AND METALS COMPANY
 YOUNG BROTHERS
- New Bedford, Mass.
 Detroit
 Bristol, Conn.
 Stamford, Conn.
 Milwaukee
 Pittsburgh
 New York City
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 Hoboken, N. J.
 Detroit

ONTARIO CHAPTER

DURING the past month, the members of the Ontario Chapter have been actively expanding their chapter in the vicinity of Hamilton, Brantford, Galt, Guelf, Kitchener and London. The response to this work and the interest shown in the A. S. S. T. in this extended field has been most gratifying. The support of the industries has been outstanding. The chapter roll as it stands today numbers 113 members, of which 13 are sustaining or firm members.

The opening meeting in the new field was held on Wednesday, December 12, at the Royal Connaught Hotel, Hamilton. A party of 160 sat down to dinner and more came in later. The meeting was opened by Hugh F. Davis, vice-chairman, who welcomed the group and thanked everyone for the hearty response to the work of the chapter. H. Kenneth Briggs, assistant national secretary, reviewed the work of the A. S. S. T. showing its aims and functions. W. O. Oliver, chairman of the chapter, introduced J. A. Succop, chief of research of the Heppenstall Forge and Knife Company, Pittsburgh.

Mr. Succop showed a very interesting film describing the making of die blocks and showing their uses. The film also showed the high spots in the manufacture of shear knives. Mr. Succop emphasized the extreme care that is necessary to make a quality steel tool of any sort, be it a lathe tool, die block or reamer. His comments on the use of forging dies were very useful and instructive.

The plan of this expanded Ontario Chapter is to meet alternately one meeting in Toronto and one at Hamilton. At present the vice-chairman is a Hamilton man, and the chairman a Toronto man. Next year these offices will be rotated and a new schedule of meeting places adopted to best serve the interests and location of our members.

This meeting was a great success, and we are confident that the industrial Ontario will gain much from the establishment of the A. S. S. T. in their midst.

ENGINEERING EXTENSION DIVISION

THE Engineering Extension courses given by Prof. John F. Keller under the auspices of the A. S. S. T. and with the co-operation of Purdue University, are nearing completion for the year 1928. The totals registered this year are slightly in excess of the registration last year, 1,282 this year against 1,211 for last year. The first series of lectures was completed with an average attendance of 90 per cent, an excellent showing.

The second series of lectures is nearing completion, figures being given below for both series of lectures to date.

Lecture Series I constitute the cities of Springfield, Hartford, New Haven, Bridgeport and Worcester, with a total enrollment of 626 and an average attendance of 90 per cent.

Lecture Series II constitutes the two cities of Bethlehem (4 classes) and Newark, with a total enrollment of 657. This series is now in progress.

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